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PILOT INVESTIGATION OF A REMOTELY PILOTED VEHICLE REMOTE OPERATOR'S STATION

Volume I - Simulation Report

Crew Systems Integration Branch
Flight Control Division

October 1976

TECHNICAL REPORT AFFDL-TR-76-103

Final Report for Period February 1974 - January 1975

AIR FORCE FLIGHT DYNAMICS LABORATORY
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A simulation study was performed to address issues related to a remote operator's interface with an automatic landing system for remotely piloted vehicles (RPV). Specifically, supervisory override and remote control modes, remote operator performance associated with various levels of control, and control/display adequacy were addressed. Throughout the simulation, alternative control modes were implemented and used to perform remote control of an RPV during the takeoff and landing portions of a mission. The supervisory over

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20. override function proved helpful during localizer and glideslope capture, while no single remote control mode was determined as superior. Preferred pitch control modes were narrowed to proportional pitch attitude and flight path angle. The control/display complement was found to contain adequate information, but particular display properties were found to be deficient. The results of this simulation were incorporated and the resulting console was validated in a flight test (Volume II of this Technical Report).

FOREWORD

This technical report documents the results of a simulation investigation of remote operator (RO) control/display issues associated with the conventional recovery of remotely piloted vehicles (RPVs). The objective of this effort was to investigate, through simulation and flight test, the RO's role, function and requirements as applied to his interaction with an Automatic Landing System (ALS).

The work was performed by the Crew System Integration Branch, Flight Control Division, Air Force Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The work was conducted in conjunction with the RPV/ALS Program managed by Mr. A. Smitchens of the Air Force Flight Dynamics Laboratory. Mr. D. Frearson of the Crew Systems Integration Branch monitored the work reported.

The authors wish to express their appreciation to the following individuals of the Integration and Analysis Branch (FGD), without whom this evaluation could never have taken place: Capt. Luis Machuca, Mr. Uldis Plate, and Mr. Fred UnFried.

A special thanks is extended to Mr. Jack Barry (FGT) for his support in our times of need.

The report covers work conducted during the period of February 1974 to January 1975.

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SECTION I

INTRODUCTION

This report provides information on issues investigated during simulation studies of an Automatic Landing System (ALS) and a Remote Operator's Station (ROS), through which a ground-based operator monitors and provides inputs to a Remotely Piloted Vehicle (RPV) during takeoff and recovery operations.

1. BACKGROUND

From March to July 1973, the Air Force Flight Dynamics Laboratory (AFFDL) conducted the first phase (Phase I) of a two-phase program directed towards the establishment of initial requirements for a RPV ALS. The system was specified to operate (a) strictly in an autoland mode, (b) with Remote Operator (RO) interface via a Supervisory Override (SO) function, or (c) split-axis control between the RO and the ALS.

The complexities of ground recovery and recovery area operations were recognized, and Phase I concluded that further investigation into the role, function and requirements of a RO in this type an environment was necessary.

2. PROBLEM

Generally, the RO was identified by Phase I as required to perform RPV system initialization, system monitoring, flight path monitoring and remote control, when necessary. In view of these RO tasks, the AFFDL Crew Systems Integration Branch (AFFDL/FGR) of the Flight Control

Division was asked to investigate the RO's role, function and requirements as applied to his interaction with the ALS. Also, AFFDL/FGR was assigned the task of investigating the control/display and pilot factors issues associated with the development of a Remote Operator's Station (ROS).

These tasks were carried out under Phase II of the AFFDL/Autoland Program, a program dedicated to investigating specific RO/ALS issues. The Phase II program called for a ground-based simulation, resultant system modifications, and a flight test.

3. OBJECTIVES

As a result of Phase I, the following were established as primary objectives of the Phase II RO/ALS investigation.

1. Determination of the capability of the RO to interface with the SO function of the ALS.

2. Determination of a preferred control mode in each of the axes (pitch, roll, and yaw) for remote control.

3. Determination of RO's role under various degraded control conditions (single, double, or triple axis failures).

4. Determination of the suitability of the controls and displays selected for the RO to fulfill his assigned tasks.

4. FUNCTIONAL ALS DESCRIPTION

The ALS is basically an L-1011 control system modified for a Compass Cope type vehicle. The ALS design was initiated by Collins Radio Company and finalized by the AFFDL Control Criteria Branch. The system design provides a fully automatic solution to the landing problem consistent with commercial airline/Federal Aviation Administration (FAA) philosophy. RO control modes were identified by FGR and integrated with the ALS design for simulation investigation. A block diagram of the RO/ALS interface is shown in Figure 1.

For autoland operation, the RO and supervisory inputs are disabled; for autoland/supervisory, the RO supervisory inputs are enabled. Remote control assumes that one axis of the outer loop computation has failed and the RO must fly that axis remotely through the remote command inputs.

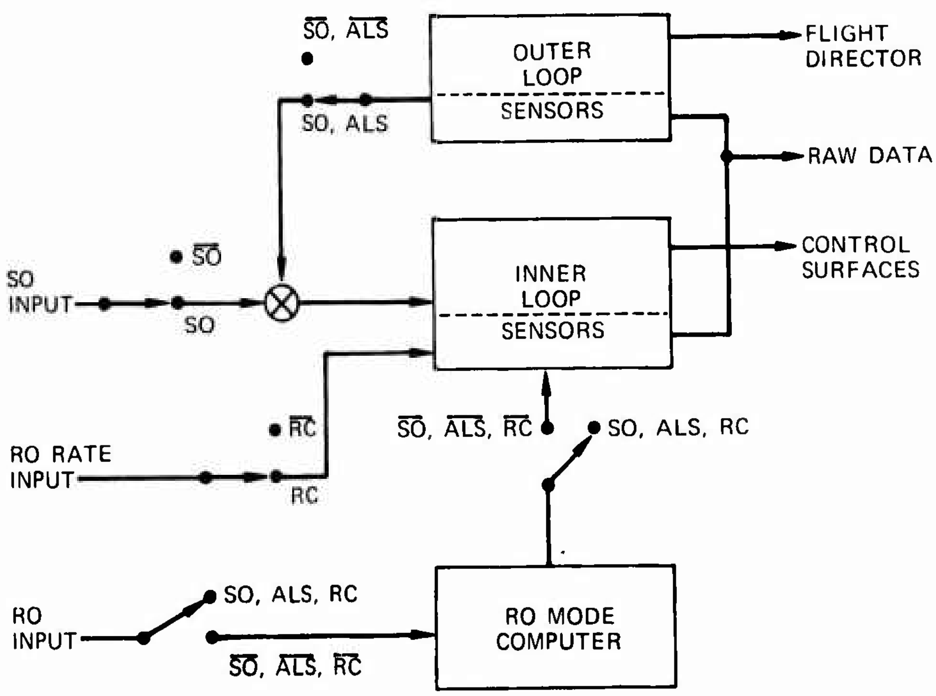


Figure 1. Remote Operator/Automatic Landing System Interface

SECTION II

APPROACH

This section identifies the particulars of the simulation. The hardware description, experimental procedures, experimental design, data reduction and analysis, and symbology/criteria are discussed in detail.

1. HARDWARE DESCRIPTION

1.1 AERODYNAMIC MODEL

The aerodynamic model used throughout the simulation was that of the Teledyne Ryan Compass Cope vehicle, a high-altitude long endurance RPV (see Figure 2). Specifications of this vehicle are given in Table I.

1.2 REMOTE OPERATOR'S STATION

The Remote Operator's Station (ROS) is a wrap-around console designed for the side-by-side seating of two operators; one, the primary operator and the other a systems/performance monitor (see Figure 3). The primary operator, or remote operator (RO), is located on the right side of the ROS to allow for the use of a side-arm controller without compromising the possibility of sharing the center console functions with the systems monitor on the left.

The control/display arrangement is such that the RO performs the system initialization, monitoring, and remote backup functions. The systems monitor is considered an ancillary observer and could be used to perform the communication tasks as well as others not requiring the developed skill of the RO.

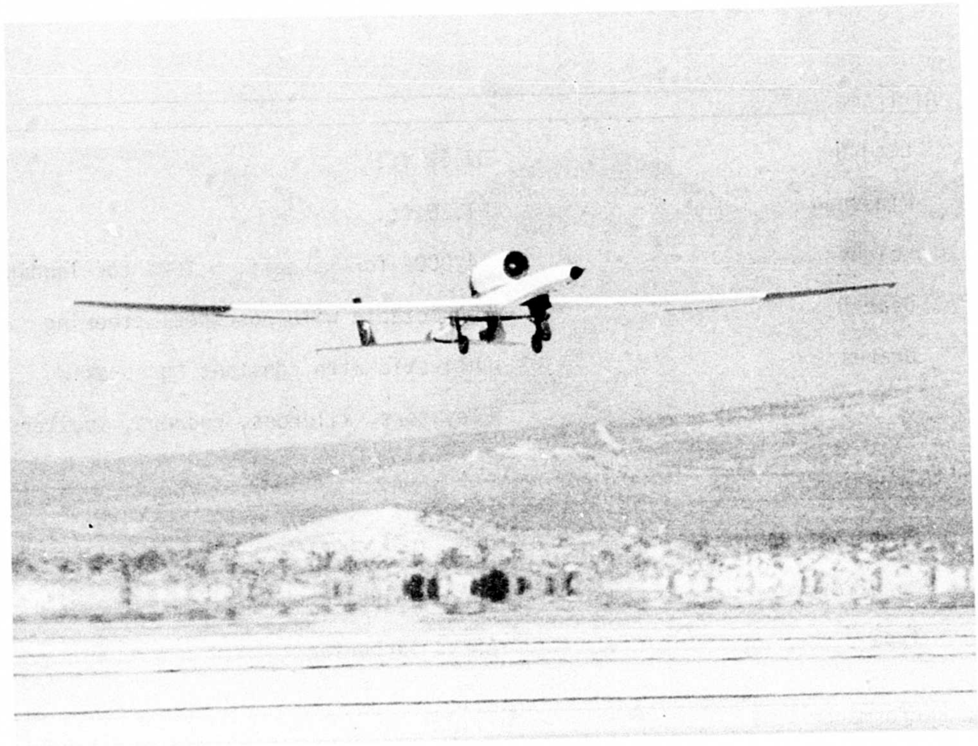


Figure 2. Teledyne Ryan Compass Cope

TABLE I

TELEDYNE RYAN COMPASS COPE SPECIFICATIONS

Airframe	
Length	37.32 ft.
Wingspan	81.20 ft.
Weight	14,000# for takeoff; 5,700# for landing
Gear	Retractable with nosewheel steering
Brakes	Anti-skid with constant "g" braking
Control surfaces	Elevators, ailerons, rudders, spoilers
Powerplant	
Number of engines	One
Manufacturer	Garret AiResearch
Type	ATF-3 Turbo-fan
Performance	
Takeoff Speed	120-140 kts
Landing Speed	100 kts

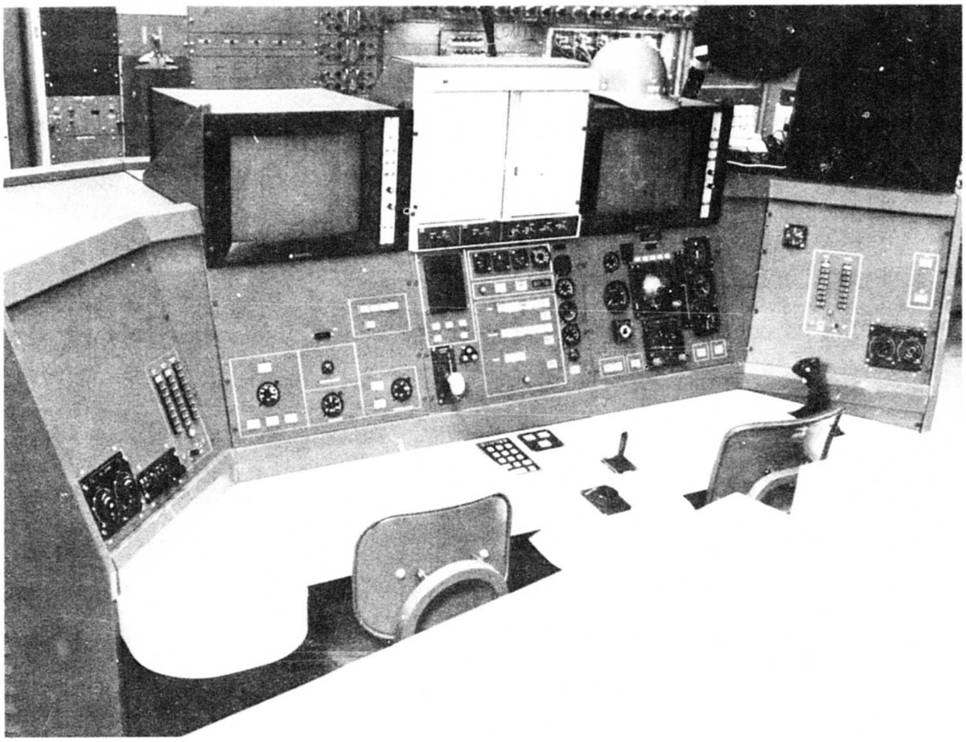


Figure 3. Remote Operator's Station

The focal point of the ROS is the instrumentation used on the primary instrument panel (see Figure 4). This instrumentation incorporates display features found to be usable for instrument approaches during the Pilot Factors (PIFAX) Program conducted by the Air Force Flight Dynamics Laboratory in the middle 1960s. A more detailed description of the ROS and its controls and displays may be found in Appendix A.

1.3 THE RO CONTROL MODES

The RO control modes used during the simulation are as follows:

1. ALS with supervisory override. In this mode the ALS is not failed; however, a supervisory override capability is enabled. The RO can make supervisory commands through the side stick controller. The inputs are summed with the automatic command. Override of power was not investigated. The override commands are as follows:

    a. Pitch - input to the autoland pitch rate loop.

    b. Roll - input to the autoland roll attitude loop.

    c. Yaw - input to automatic yaw loop which provides proportional rudder during localizer track and proportional yaw rate during align.

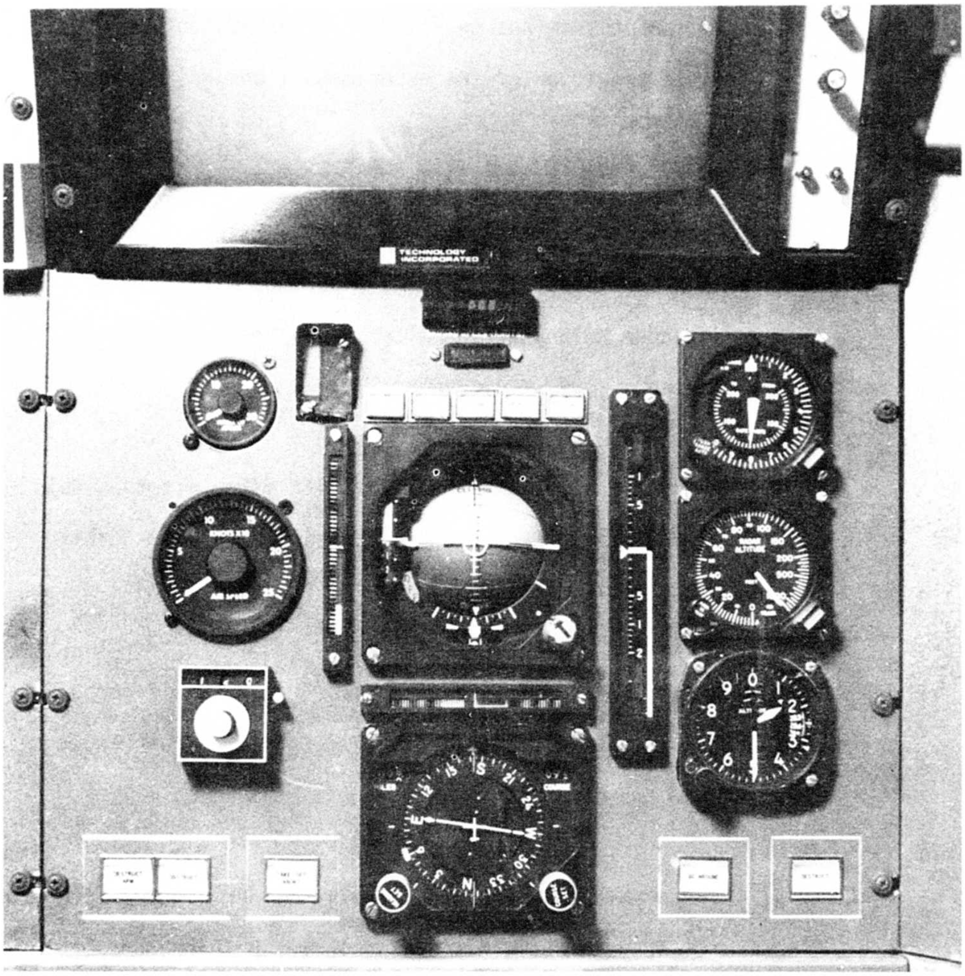


Figure 4. Flight Instrument Panel

2. Remote pitch. In this mode the ALS is uncoupled and remote inputs are made through the side stick controller. The remote pitch alternatives (not selectable by the RO, but selected as a variable condition of the experimental design) were as follows:

   a. Proportional pitch attitude (PPA) - Pitch attitude change is proportional to stick displacement with trimmed pitch attitude held when the stick is in the neutral position (detent).

   b. Proportional pitch rate (PPR) with pitch attitude hold - Pitch rate is proportional to stick displacement with pitch attitude held when the stick is in detent.

   c. Proportional flight path angle (FPA) - FPA is proportional to stick displacement with trimmed path angle held when the stick is in detent.

   d. Trim - Discrete steps or slew in either pitch attitude or flight path angle are available for both proportional pitch attitude and FPA.

3. Remote roll. In this mode, as in pitch, the ALS is uncoupled and inputs are made by the RO through the side stick controller. The remote roll alternatives (again, a variable of the experimental design) were:

   a. Proportional roll attitude (PRA) - Roll attitude is proportional to stick displacement with wings level when the stick is in detent (with heading held by the ALS).

   b. Proportional roll rate (PRR) with roll attitude hold. Roll rate is proportional to stick displacement with roll attitude held when the stick is in detent.

4. Remote yaw. Only one remote yaw control mode was evaluated. With the ALS uncoupled, a yaw rate proportional to the yaw controller displacement is commanded by the RO. With the stick in detent, heading hold mode is engaged.

5. Remote power. Only one remote power control mode was evaluated. With the ALS uncoupled, power was proportional to the power lever angle (PLA). The PLA is controlled at the ROS via a throttle lever which commands an increase or decrease of PLA at a constant rate (PLA is proportional to RPM).

1.4 MICROWAVE LANDING SYSTEM MODEL

A microwave landing system (MLS) model was selected to provide the approach and landing guidance to the RPV. This selection was based upon the projected MLS technology level to coincide with the operational Compass Cope RPV, modularity of the system, and a wide range of operational capability (Category I to Category III).

The MLS is an air derived position data system designed to operate at C or K band frequencies. The landing guidance system defines the RPV position within the system coverage in spherical coordinates (azimuth angle, elevation angle, and range). Using this information, the airborne system determines the RPV's position from the desired approach path and generates appropriate signals to command the vehicle.

The MLS system characteristics for the simulation (see Figure 5) were:

Azimuth Limit ....$\pm 10°$

Elevation Limit ....$+10°$ to $+1°$

Nominal Glideslope ....$+4°$

Range 12.5NM

1.5 SIMULATION FACILITY

The simulation facility utilized for this portion of Phase II of the RPV/ALS Program was that maintained by the Flight Systems Integration Branch of the Air Force Flight Dynamics Laboratory. Figure 6 is a block diagram of the ROS/Simulation Facility interface.

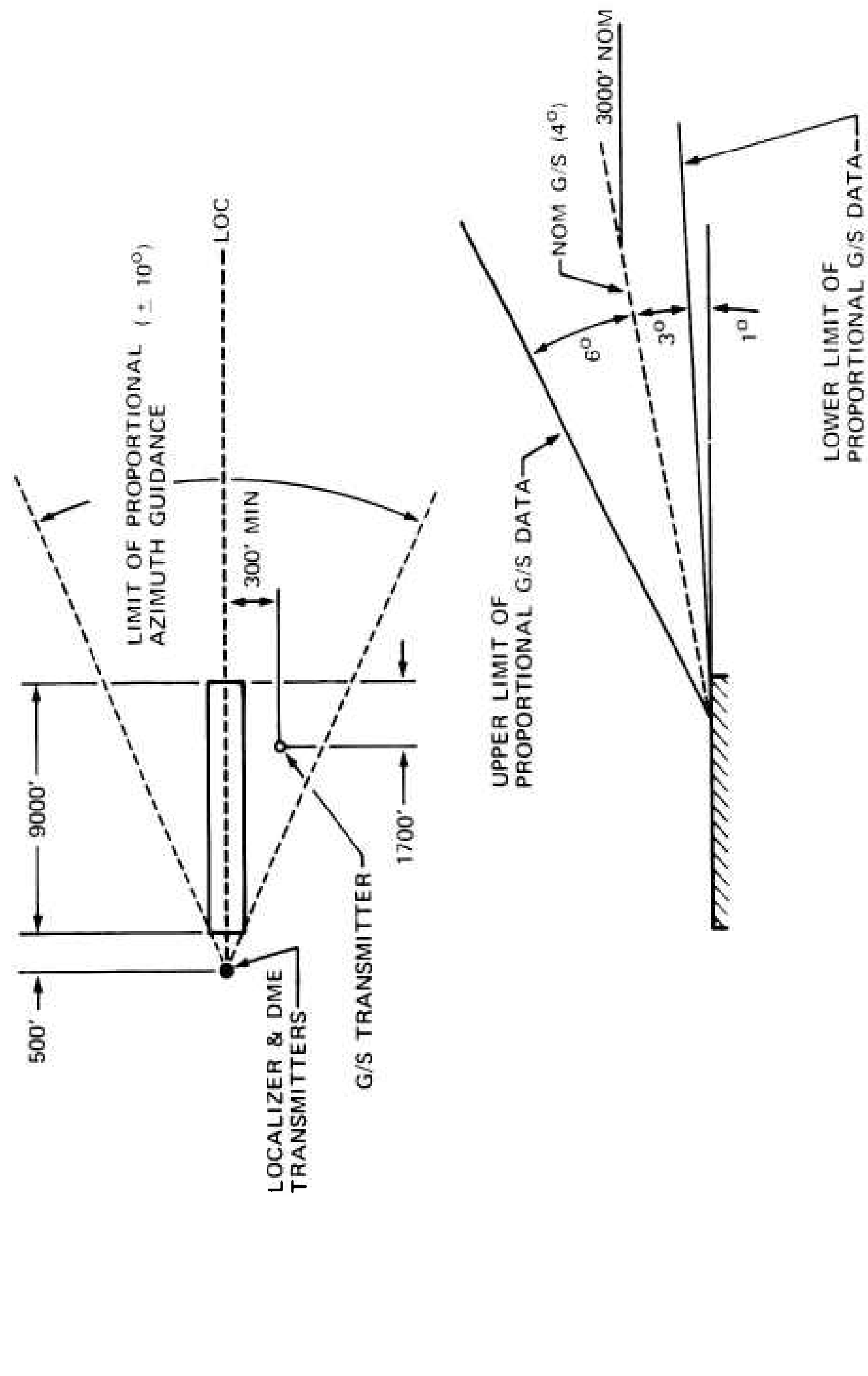


Figure 5. Microwave Landing System Geometry

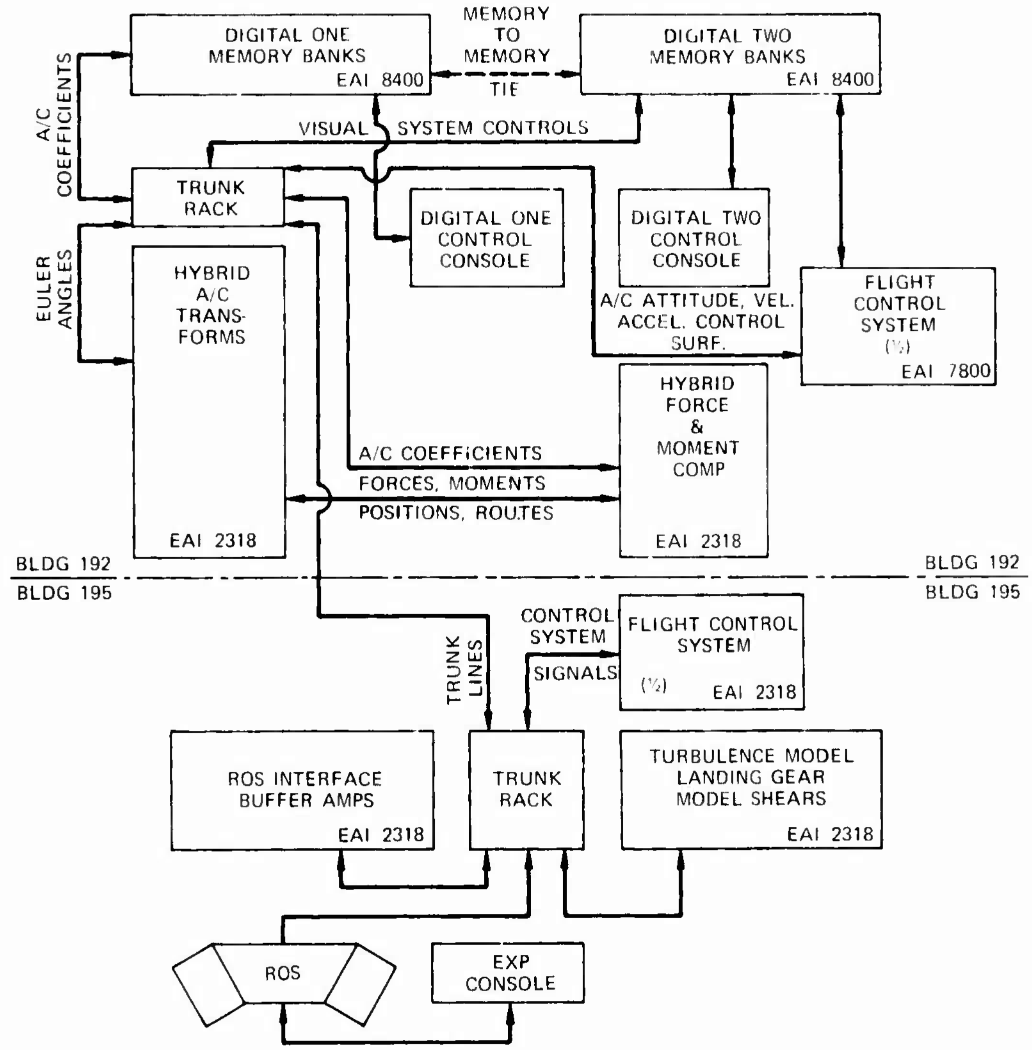


Figure 6. Remote Operator's Station/Simulation Facility Interface

2. EXPERIMENTAL PROCEDURES

In order that a structured approach to the problem be maintained, the simulation was divided into three phases: Study, Pre-test, and Test.

2.1 STUDY

The study addressed the requirements of total system familiarization, the establishment of proper piloting techniques, ground operations, and the procedures to be used in the subsequent phases. Support contractor test pilots, experienced in instrument approaches and the PIFAX program, performed system initialization, taxied, monitored automatic takeoffs and landings, and performed remote takeoffs and landings with various combinations of control modes and axes failures. The axes failures (combinations of pitch, roll, yaw, and power) were inserted randomly above and below 200 feet. All flights were made under "worst-case" environmental conditions (CAT IIIb visibility*, winds, gusts, shears and turbulence).

The pilots and observers recorded their comments from which conclusions to the study objectives were drawn.

Subject descriptions and profiles flown, along with procedures, design, dependent variables, and data collection, reduction and analysis techniques used in the Pre-Test and Test are covered in the following paragraphs.

---

*0 ft decision height, 150 ft runway visual range.

Four subjects (two from TAC and one each from SAC and AFSC) participated in the Pre-test and Test phases of the simulation program. Based upon the ROS design and available time, specific selection criteria were established. Three of the selected subjects had a current instrument rating and jet experience. The fourth subject was not instrument rated, but had other experience, background, criteria and qualities considered important to the program. A complete discussion of the subjects' backgrounds may be found in Appendix B.

2.2 PRE-TEST

The Pre-test began with system familiarization for all subjects. This consisted of automatic approaches under a variety of visibility and weather conditions. Training to equalize learning effects was then administered. Due to the issues and time constraints, subjects were only exposed to the approach and landing segment. The investigation of the takeoff segment was reserved for the Test phase. Axes failures were inserted thirty seconds after the start of each run, allowing the system to stabilize and workload to be maximized over the whole profile.

During the Pre-test, the subjects were exposed to the full range of environmental conditions from Visual Meteorological Conditions (VMC) with winds (for the familiarization portion) to CAT IIIb visibility conditions with winds, shears and turbulence (for the training and data collection portions).

Data were collected on parameters relating to RO performance, autoland performance, and workload via FM tape, video tape and event and response timers. Pilot comments with regard to task complexity and adequacy of the ROS were recorded on audio tape.

It was obvious from initial analyses of the Pre-test data that the proportional attitude rate control mode created a consistently excessive workload across all four subjects. This fact, coupled with negative subject comments, caused this control mode to be eliminated from further consideration prior to the test. The flight director commands implemented in simulation were the ALS outputs which were not suitable for RO control. As a consequence, the proportional attitude with flight director control mode was eliminated from the Test phase.

The Pre-test profile extended from localizer intercept at approximately 90 degrees to the runway centerline to touchdown (about 8 miles of range). The lateral and vertical guidance was provided by simulating Microwave Landing System (MLS) signals. A 4-degree glideslope was flown with a 150-foot alignment to runway heading, 50-foot flare and 5-foot deroll. The specific type of flare maneuver (one-step, two-step, exponential, etc.) was not specified; however, most subjects chose a "multi-step" flare.

2.3 TEST

The Test constituted the main effort of the simulation and was conducted using essentially the same methodology as that used in the

Pre-test except that a familiarization step was not given. All four subjects were exposed to the approach and landing segment. Two pilots were selected at random to perform takeoffs. Since the Pre-test showed that localizer capture was a task easily performed by all subjects, and simulation time was at a premium, the test runs were shortened somewhat. Each subject began his run tracking localizer approximately 6.5 miles out prior to glideslope capture.

Based upon Pre-test results, control modes were reduced to proportional pitch and roll attitude without flight director, proportional flight path angle, and proportional yaw rate. This gave a total of nine possible axis failure/control mode combinations, identified in Table II. Again, all axis failures were inserted thirty seconds after the start of each run. For the takeoff segment, axis failures were inserted randomly before and after rotation speed.

Environmental conditions were the same for both takeoff and landing. "Worst case" conditions were used with the addition of random localizer and glideslope beam noise.

Test data were collected using the same equipment as in the Pre-test. Subject comments were continuously recorded.

At the completion of simulation, an oral debriefing was held with the subjects, and comments were recorded on audio tape. Additionally, a questionnaire covering the independent variables, pilot factors, and miscellaneous issues was administered to each subject.

TABLE II

INDEPENDENT VARIABLES

Control Modes	Axis Failures		
	Single	Dual	Triple
Proportional Pitch Attitude Without Flight Director	Proportional Pitch Attitude	Proportional Pitch and Roll Attitude	Proportional Pitch and Roll Attitude and Yaw Rate
Proportional Roll Attitude Without Flight Director	Proportional Pitch Rate	Proportional Pitch and Roll Rate	Proportional Pitch and Roll and Yaw Rate
Proportional Pitch Attitude With Flight Director	Proportional Flight Path Angle	Proportional Flight Path Angle	Proportional Flight Path Angle and Roll Attitude
Proportional Roll Attitude With Flight Director	Proportional Roll Attitude	Proportional Pitch Attitude and Yaw Rate	
Proportional Pitch Rate Without Flight Director	Proportional Roll Rate	Proportional Pitch and Yaw Rate	
Proportional Roll Rate Without Flight Director	Proportional Yaw Rate	Proportional Flight Path Angle and Yaw Rate	
Proportional Yaw Rate Without Flight Director		Proportional Roll Attitude and Yaw Rate	
Proportional Yaw Rate With Flight Director		Proportional Roll and Yaw Rate	
Proportional Flight Path Angle Without Flight Director			

It is appropriate at this time to identify several factors which must be considered when one is interpreting the data and subsequent results. As a result, these data are not considered adequate to predict operational performance. The data are adequate to support the decisions in the control/display area.

First, at no time was there any intent to set up a "man versus machine" contest. It was not our purpose to say which is better and, therefore, should be implemented. Rather, the intent was to investigate the interface requirements necessary to have a remote operator function with an autoland system.

Second, this was a highly complex simulation to mechanize. Limited aerodynamic parameters were available, and a good many compromises and projections had to be made. As a result, the simulation was not optimized at the outset and, in fact, adjustments had to be made throughout the Study and Pre-test. Consistency and stability was limited in the Familiarization and Pre-test phase of the simulation.

Third, and related to the foregoing, were the effects of a parallel effort by the Control Criteria Branch of the Air Force Flight Dynamics Laboratory to develop and define the requirements of the autoland system. Much was known about the candidate autoland system, but the autoland system and the remote control system had never been "married" until the simulation. Solving the problems associated with mating the two and with developing some consistency of

performance across the four control modes was a formidable task, which affected the handling and "flyability" of the aircraft throughout the Study and Pre-test.

Fourth, the only available method of comprehensive data collection upon the various performance parameters was the recording of analog signals on FM tape. Stripping and reduction, however, required the use of digital computers, thus necessitating an intermediate step of digitizing the analog data. This process, by its very nature, involves a loss of accuracy. The full extent of the impact on the results cannot be accurately determined, but adjustments to the process were made between the Pre-test and Test phase, and it is felt that test data are as accurate as possible.

Fifth, the full effect of the environmental conditions must be taken into account. It must be remembered that each RO was required to fly an unfamiliar vehicle through very difficult wind and visibility conditions, using primarily raw data presented to him in an environment totally devoid of the tactile and aural cues normally associated with flight. The wind, gusts and turbulence, and, in the test, beam noise were mechanized using a prerecorded noise tape output inserted into an analog model. It was discovered during the Pre-test that only certain portions of the tape were free enough of anomalies and had a reasonable magnitude of variation to be practically useful. As a result, a certain unwanted but unavoidable amount of detectable environmental repeatability was injected into the simulation. Also, there was a warm-up problem with the noise tape which caused biases in the noise.

Finally, the limited number of subjects available and the unequal exposures across all failure levels, caused by mechanical failures and time constraints, limited the type of statistical analyses which could be done. While a lower level of analysis is sufficient for the current effort, more detailed simulation studies with sufficiently large subject populations will be required to establish a firm statistical base.

In a report of this nature it is desirable to present the data in as meaningful and easily understood a form as possible. Normally, this involves the use of graphs and tables. In the present case, however, due to frequent wide variability within some performance parameters, means and standard deviations did not show a consistent picture of the data. For this reason, the median was selected as the primary tool for presentation in the Results Section.

Subjective and objective data were collected throughout simulation, and subsequent comments are based on both. The preponderance of usable objective data is that collected on FM tape during the Test phase. Subjective data were collected via questionnaires, recorded comments and debriefing. The total package is not included in this report. Only that data which directly relates to the issues under investigation in the simulation are discussed.

3. EXPERIMENTAL DESIGN

The designs of the Study, Pre-test, and Test phases were experimental treatment by subject. All subjects were exposed to all axis

failure/control mode combinations an equal number of times for the approach and landing. Experimental block diagrams along with additional descriptions may be found in Appendix C.

Table III lists the independent variables identified for use during selected portions of the simulation.

The dependent variables used measured primarily RO performance through aerodynamic parameters and space coordinates. The primary performance parameters and coordinates used are given in Table IV.

4. DATA REDUCTION AND ANALYSIS

The dependent variables were recorded on FM tape for each data run. The tapes were processed through a digital computer and presented as data blocks at selected events and as time statistics. The following analyses were performed on the data:

1. Medians and ranges calculated for lateral displacement, vertical velocity, heading error, and range at 100 feet above ground level.

2. Medians and ranges calculated for lateral displacement, vertical velocity, heading error, range, crosstrack rate, pitch attitude, pitch rate, and roll attitude at touchdown.

TABLE III

INDEPENDENT VARIABLES

Visibility	Winds	Flight Segment
Visual	25 knot headwind	Approach/Landing
	15 knot crosswind	
Category IIIb	10 knot tailwind	Takeoff
	turbulence gusts	

TABLE IV

DEPENDENT VARIABLES

Name	Symbol
Pitch Attitude	θ
Roll Attitude	ϕ
Yaw Attitude (Heading)	ψ
Vertical Velocity	$\dot{h}$
Crosstrack Rate	$\dot{y}$
Lateral Displacement	y
Range	x
Altitude	h
Airspeed	Vias
Pitch Rate	$\dot{\theta}$

3. Landing success rate tables, for three levels of success, for range and lateral displacement at 100 feet above ground level.

4. Landing success rate tables, for three levels of success, for range, lateral displacement, vertical velocity, pitch attitude, roll attitude, heading error and crosstrack rate at touchdown.

Also, subjective data were collected on rating scale questionnaires and used to assist in the discussion of results and recommendations.

5. SYMBOLOGY AND CRITERIA

All of the performance parameters used in the following sections have symbols which will be used. Table V lists these parameters and their respective symbols.

Criteria by which to determine success or failure with regards to the performance on each parameter were needed. A "window" was established at 100 feet above ground level (AGL) (Table VI). Three levels of criteria were chosen to compare touchdown parameters. They are:

Level I - on the runway within structural limits of the vehicle (marginally acceptable),

Level II - moderately acceptable,

Level III - highly acceptable.

TABLE V

PERFORMANCE PARAMETERS, SYMBOLS AND NULL VALUES

Parameter	Symbol	Null Value
Longitudinal Dispersion	X	X = 0 at glidepath intercept point (GPIP)
Lateral Dispersion	Y	Y = 0 at runway centerline
Vertical Velocity	h	h = 0 at touchdown
Pitch Attitude	θ	0 degrees
Pitch Rate	$\dot{\theta}$	0 degrees/sec
Roll Attitude	ϕ	0 degrees @ wings level
Crosstrack Rate	y	0 ft/sec
Heading Error	ψ_{ε}	0 degrees when A/C heading = runway course

TABLE VI

100 FT AGL WINDOW CRITERIA

Parameter	Criteria
X	-1600 ft to -1270 ft measured from GPIP (corresponds to Z ±11.5 ft)
Y	±65 ft measured from extended runway centerline

The allowable range for each parameter is listed by criteria level in Table VII.

TABLE VII

TOUCHDOWN CRITERIA LEVELS

Parameters	Level I	Level II	Level III
y	±55 ft	±35 ft	±25 ft
x	$-1000\text{ ft} \le x \le 2000\text{ ft}$	±1000 ft*	±500 ft*
$\dot{h}_{max}$	10.5 fps	7.5 fps	4.5 fps
θ	$0° \le \theta \le 6.5°$	$0° \le \theta \le 6.5°$	$0° \le \theta \le 6.5°$
ψ_ε	±5°	±3.75°	±2°
ϕ	±4.5°	±3.5°	±2°
$\dot{y}$	±9 fps	±5.5 fps	±3.5 fps

*Denotes dispersion about nominal touchdown point at x = 1000 ft.

SECTION III

RESULTS

This section presents the "what happened" in terms of each issue. For brevity, the data and a detailed discussion of the results are not presented here, but may be found in Appendix D.

1. REMOTE OPERATOR (RO) PERFORMANCE USING SUPERVISORY OVERRIDE (SO)

The ROs' use of Supervisory Override (SO) centered around their confidence in the ALS and their ability to use SO. Early in simulation, the ROs felt they could assist the ALS, but found themselves "chasing" it instead. Throughout simulation a trend of decreased RO use of this mode continued, until use of SO virtually ceased towards the end of simulation. At this time, RO activity was limited to aiding beam capturing, while the ALS flew the rest of the approach. Subjective opinion indicates about a ten percent usage of SO, with the preference that it be "on" rather than having to select the feature. The ROs' preference (Table VIII) for decoupling and flying remote, as opposed to using the SO feature, further reiterates the ROs' feelings towards this mode.

TABLE VIII. SUPERVISORY OVERRIDE VS. REMOTE CONTROL COMMENTS

<u>Supervisory Override Vs. Remote Control</u> - Subjects were asked about their preferences with regard to flying in a supervisory override configuration or decoupling and continuing in a remote control mode subsequent to any single axis failure. One subject indicated a preference for supervisory override; three chose the decouple/remote control option.

2. RO PERFORMANCE USING REMOTE CONTROL MODES

Two modes were eliminated after the Pre-test. Proportional attitude with a flight director was eliminated because of its implementation (commands generated were actually the outer loop commands of the ALS) and subsequent lack of optimization for RO control. Proportional Rate was eliminated due to its unacceptability to the ROs, who placed it last in their rating of the control modes. This issue in the Test phase, therefore, turned into a comparison of proportional pitch attitude versus proportional flight path angle.

At 100 feet AGL, the median performance of both control modes for range is equally acceptable. Interestingly, both control modes tend to be flown on or below the glideslope (as indicated by the range (x) values in Table IX).

Lateral dispersion data at 100 feet AGL reflect essentially the same results. Median values are equally varied with the dispersion slightly tighter in flight path angle. Table IX shows median values for lateral dispersion.

At touchdown (TD), both pitch modes show a tendency to land on the order of 300-400 feet past the GPIP, which is acceptable. However, for all combinations the dispersions are high, indicating a problem in repeatable, acceptable landings as far as longitudinal dispersions are concerned.

Vertical velocity at TD is obviously smaller with the flight path angle control mode. This stability of difference across all combinations indicates a consistently superior control of vertical velocity by flight path angle.

Pitch attitude measures the relationship of the longitudinal axis of aircraft to the control mode. The initial result in looking at this median data is the slightly smaller pitch angle by proportional pitch attitude across three of the four combinations. Also, the pitch attitude ranges reflect this in the smaller dispersion values for proportional pitch attitude.

Median and range values for the TD parameters are shown in Table X.

At the completion of simulation, the subjects responded to a questionnaire which, in part, addressed the issue of RO performance in the alternative control modes. They universally gave the most favorable ratings to the flight path angle control mode in the areas of tracking (workload), control authority, vehicle responsiveness and overall personal preference (Table XI). Proportional pitch rate and roll rate received the least favorable ratings in the same areas.

This was a considerable change from their verbal comments at the beginning of simulation where their reaction to the flight path angle mode was less than complimentary. This turned out to be primarily a

TABLE IX

RANGE AND LATERAL DISPLACEMENT VS. CONTROL MODE

PARAMETERS	CONTROL MODE COMBINATIONS									
	θ	γ	Φ	$\theta\Phi$	$\gamma\Phi$	$\theta\Psi$	$\gamma\Psi$	$\Phi\Psi$	$\theta\Phi\Psi$	$\gamma\Phi\Psi$
RANGE - ft. (x)	-1400(1200)	-1400(600)	×	-1800*(1600)	-1400(1200)	-1800**(800)	-1500(400)	×	-1600*(2000)	-1600*(1000)
LATERAL DISP (y)	×	×	×	20(130)	30(120)	×	×	×	-30(160)	0(150)

× Indicates Control Mode Combination Does Not Apply To Parameter

* Indicates an Upper Limit of the 100 Ft AGL Window

** Indicates Outside the Limits of the 100 Ft AGL Window

TABLE X

LONGITUDINAL DISPERSION, VERTICAL VELOCITY AND PITCH ATTITUDE VS. CONTROL MODE FOR TOUCHDOWN

PARAMETERS	CONTROL MODE CONFIGURATION									
	θ	γ	Φ	$\theta\Phi$	$\gamma\Phi$	$\theta\Psi$	$\gamma\Psi$	$\Phi\Psi$	$\theta\Phi\Psi$	$\gamma\Phi\Psi$
LONG. DISP. - ft. (x)	300(1800)	400(1800)	×	200(2800)	400(3700)	200(1800)	800(2000)	×	-100(3200)	200(1400)
VERTICAL VEL. - fps ($\dot{h}$)	5(7)	2.5(7)	×	6.5(8)	5(8)	4.5(5)	2.5(4)	×	6.5(10)	5(7)
PITCH ATTITUDE - deg. (θ)	3.5(5)	5.25(6)	×	3(3.5)	2.75(5)	3(5)	4(4.5)	×	2.75(4.5)	3.5(9.7)

× Indicates Control Mode Combination Does Not Apply to Parameter

NOTE: Median values presented with total dispersion in parentheses.

TABLE XI

CONTROL MODE TRACKING, CONTROL AUTHORITY, VEHICLE RESPONSIVENESS AND PREFERENCE COMMENTS

TRACKING TASK

Subjects rated the tracking task for each remote control mode. The rating scale covered a range from normal to excessive.

(1) Two operators rated proportional pitch attitude at 2, while two rated it high (3). In the same range, proportional pitch rate was rated significantly higher with one subject rating it 2, two at 4 and one excessive (5). Proportional flight path angle was rated best with two subjects rating it normal (1) and two at 2. Pitch axis averages are:

Normal			High				Excessive
1		2		3		4	5
	↑ 1.5 Prop FPA		↑ 2.5 Prop Pitch Att		↑ 3.75 Prop Pitch Rate		

(2) The roll axis tracking task comparison was between proportional roll attitude and proportional roll rate. One subject rated roll attitude normal (1), two rated it high (3) and one rated it (4).

One subject rated roll rate normal (1) and three rated it excessive (5). Roll axis averages are:

Normal | High | Excessive

1 — 2 — 3 — 4 — 5

2.75 Roll Att

4.0 Roll Rate

(3) The yaw axis tracking task was rated lowest with three subjects rating it normal (1) and one rating it (2) for a 1.25 average.

Normal | High | Excessive

1 — 2 — 3 — 4 — 5

1.25

CONTROL AUTHORITY

Subjects rated control authority for each remote control mode. Average ratings for each are:

(1) Pitch Axis

Inadequate | Adequate | Excellent

1 — 2 — 3 — 4 — 5

3.25 Prop Rate

3.62 Prop Att

4.37 Prop FPA

(2) Roll Axis

Inadequate Adequate Excellent

1 2 3 4 5

1.75 Prop Rate
2.25 Prop Att

(3) Yaw Axis

Inadequate Adequate Excellent

1 2 3 4 5

3.5 Yaw Rate

VEHICLE RESPONSE

Subjects rated vehicle response for the same control modes.

Average ratings are:

(1) Pitch Axis

Unresponsive Responsive Highly Responsive

1 2 3 4 5

2.75 Prop Att
3.0 Prop Rate
4.0 Prop FPA

(2) Roll Axis

Unresponsive Responsive Highly Responsive

1 2 3 4 5

2.0 Roll Att
2.5 Roll Rate
2.75 Roll Att Override

(3) Yaw Axis

Unresponsive		Responsive	Highly Responsive	
1	2	3	4	5

3.0
Override

3.25
Remote

function of their unfamiliarity with this method of vertical plane control. However, once they fully realized what they were flying, their performance and their opinion of the mode changed significantly. Ratings of the four pitch/roll axes control modes in order of subject preference follow:

1. Proportional flight path angle (with roll attitude).
2. Proportional pitch and roll attitude without flight director.
3. Proportional pitch and roll attitude with flight director.
4. Proportional pitch and roll rate.

It should be noted that the average rating for the proportional attitude modes with and without flight director are virtually identical. Subject comments indicate that the flight director, as implemented, was unusable. However, the subjects went on to further suggest that a pitch attitude mode with a flight director may have been preferred.

3. RO PERFORMANCE VERSUS FAILURE LEVEL

The issue of RO performance under degraded ALS control was one of the primary issues investigated. For the results presented in this section, a pitch (P) failure is a combination of both proportional pitch (θ) and flight path angle (γ); a pitch roll (PR) failure is a combination of both proportional pitch roll ($\theta\phi$) and flight path angle roll ($\gamma\phi$); a pitch yaw (PY) failure combines both proportional pitch yaw ($\theta\psi$)

and flight path angle yaw ($\gamma\psi$); and a pitch roll yaw (PRY) failure is a combination of both proportional pitch roll yaw ($\theta\phi\psi$) and flight path angle roll yaw ($\gamma\phi\psi$).

As a general indicator, Figure 7 shows single, dual and three axes control success rates. A successful landing is defined as one which satisfies all the parameters of a criteria level (I, II or III).

The significance of this data is that with single axis control (P, R, or Y), we experience only eighty percent success. Three axes success percentages do not appear as expected, but show a slightly better percentage of success for the "tighter" criteria levels.

Investigation of the individual axes identifies a problem in the roll axis. The data in Figure 8 shows P, R and Y success percentages as a function of the criteria levels. The data in Figure 8 shows R consistently worse than either P or Y. In all but the most stringent criteria, R success percentages are thirty or more points off the next best, P. As the data illustrates, Y is not a problem. This data is not surprising as RO comments indicate Y as the easiest, P next and R the most difficult in terms of single axis control. Experimenter observations confirm that RO control inputs were more frequent and of greater magnitude in the following order: R > P > Y.

Investigation of the dual axes (PR, PY, RY) modes again shows the difficulty in controlling the R axis. Figure 9 presents the dual axes success percentages as a function of criteria level. Once again, the R

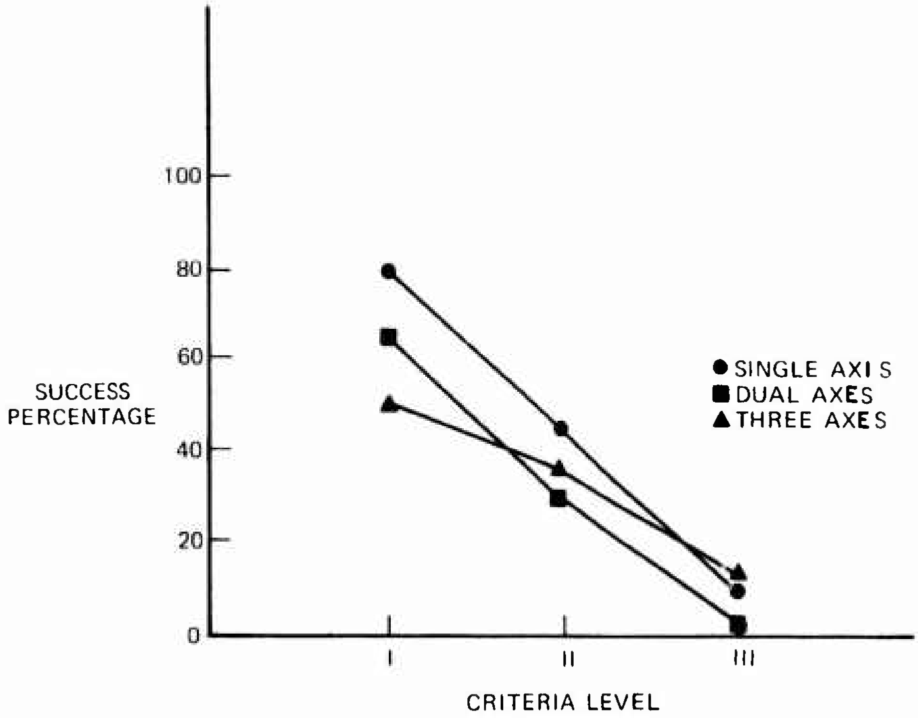


Figure 7. Single, Dual and Three-Axes Success Percentages Vs. Criteria Level

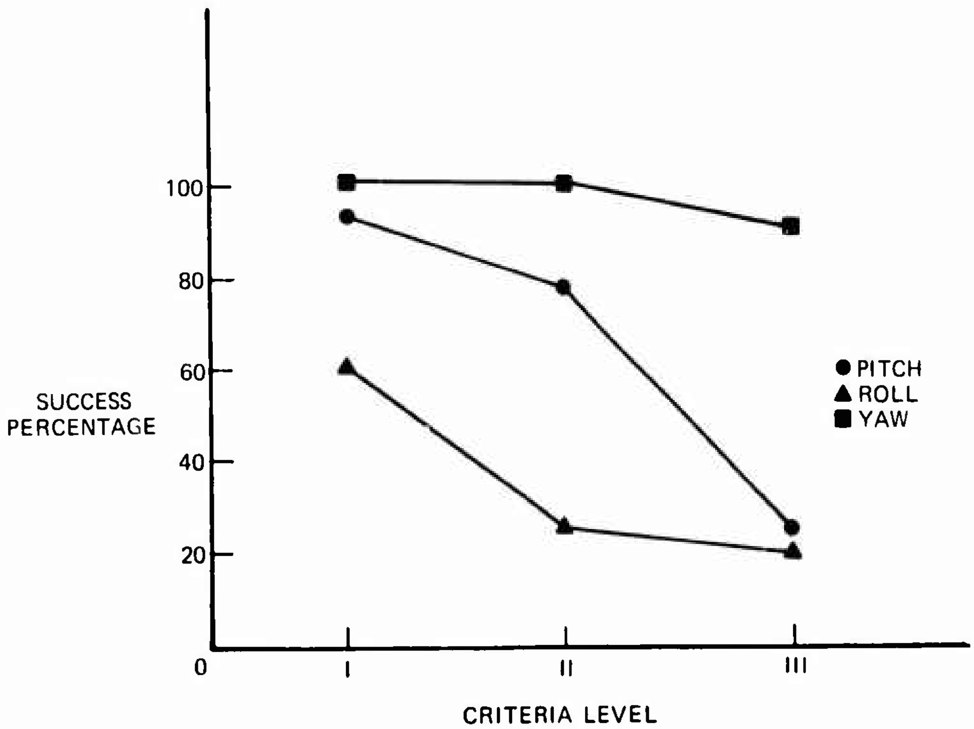


Figure 8. Pitch, Roll, Yaw Success Percentages Vs. Criteria Level

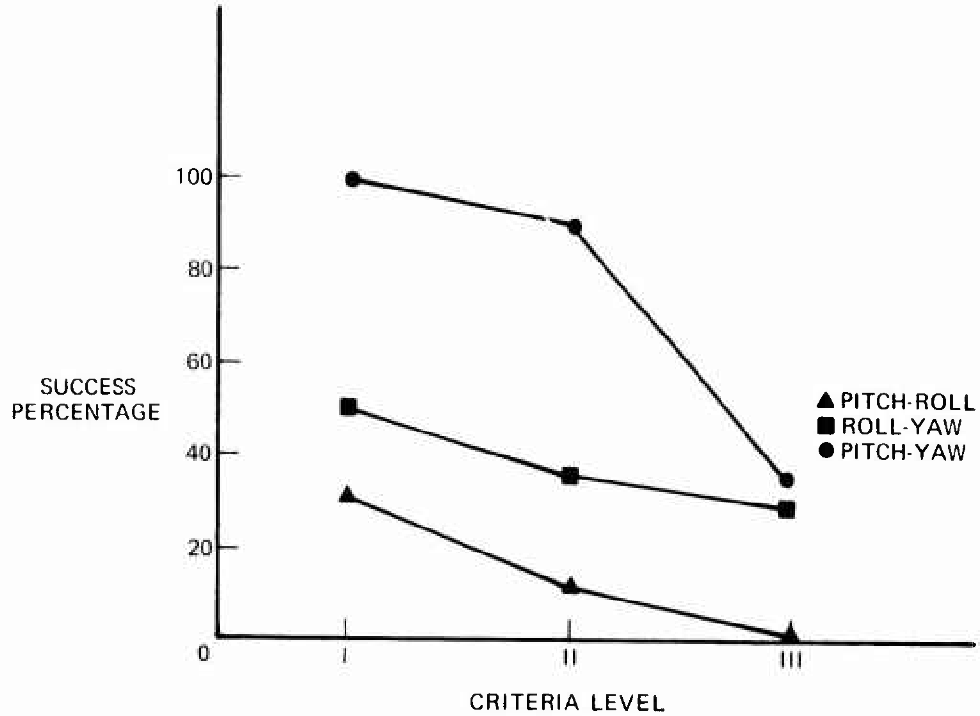


Figure 9. Dual Axes Success Percentage Vs. Criteria Level

difficulty is apparent in that the two dual axes combinations with R have success percentages consistently below fifty percent. Also, the order of success percentage is consistent across all criteria levels; i.e., PY > RY > PR.

In studying the three axes data (Figure 7), there is no apparent rationale, other than chance, that three axes performance is better than dual axes in the Level III criteria.

4. CONTROL/DISPLAY ADEQUACY

Controls and instrument displays on the console were evaluated as to adequacy in the performance of the launch and recovery task. In this section of the report, the various elements of the control/display system are be addressed in regard to operator acceptability in system initialization, ALS system monitoring, vehicle path monitoring and vehicle control. Data used in this report were obtained from subject operator comments during and immediately after completing an approach, operator questionnaires, post evaluation debriefing, and observations made by the experimenter during the test. Refer to Appendix E for operator responses in many of these areas recorded on the post-test questionnaire.

4.1 SYSTEM INITIALIZATION

System initialization tasks consisted only of switching requirements to operate the autoland panel in preparation for takeoff and landing. System initialization, in a total system context, would have required the addition of sub/support systems and a considerably longer

time period than was available in this test. Although this task was not covered in the questionnaires, the subjects indicated they were satisfied with basic autopilot setup procedures for both the launch and recovery maneuvers.

4.2 ALS SYSTEM MONITORING

Generally, operators felt that the AFCS control panel provided a satisfactory first failure warning. Subsequent to the first failure, however, most felt that the demands of flying one axis remotely could lead to missing a second or third failure indication.

Flight director steering bars presented what were, in essence, autopilot outer loop pitch and roll commands. Usefulness of these bars for monitoring AFCS operation was questionable and, therefore, seldom used by operators since they felt that subtle failures of the coupling systems probably would not be noticeable from this display.

The approach progress display mounted above the ADI provided a positive display of switching as the approach progressed from localizer capture to touchdown. Subjects commented on the lack of contrast caused by the use of blue lights in the display. They stated that under high workload conditions, they often flew through alignment, flare and touchdown either without seeing the lights or, though they knew a light came on, they could not readily identify its signal.

The most used monitors of ALS operation were the various performance displays on the panel. The results of the data with regards to these displays are discussed in the Vehicle Control portion of this section.

4.3 PATH MONITORING

For purposes of path monitoring in an automatic system context, operators were generally satisfied with the instrument displays, their arrangement, and with the parameters being displayed. They felt that, even under the turbulence conditions simulated in this test, there was sufficient information and redundancy in performance displays in each axis to monitor system performance at the "monitoring" workload level.

4.4 VEHICLE CONTROL

In this presentation of results, it is difficult to separate controls and display factors since aircraft response to control inputs and methods of measuring and presenting this response are interdependent.

The yaw rate system was used primarily for runway alignment on takeoff and landing roll and for the runway alignment maneuver normally initiated at approximately 150 feet. Subjects were satisfied with vehicle control inputs and heading control. They did, however, express some dislike for the yaw controller, indicating that physical breakout forces and gradient were too low. The operators' initial strong feelings that rudder pedals be provided mellowed as experience was gained and, by the end of the test, all felt that although some redesign was required, the side arm turn controller would be satisfactory.

The side-arm handgrip controller for pitch and bank attitude control drew several adverse comments throughout the program, primarily due to the fact the mechanical breakout, electrical dead band and force gradient were less than optimum. Switching functions and push buttons on the controller drew no adverse comment. One subject indicated that he would prefer a roll attitude trim switch in lieu of the heading trim feature provided.

Yaw trim was seldom used by the subjects. This was due primarily to the slow rate at which the system worked, wide variations in aircraft heading caused by turbulence, and the unpredictability induced by the RPV's poorly damped adverse yaw characteristic.

All subjects were favorably impressed with the pitch trim feature. In the final analysis it was used almost exclusively as a "beep" controller since operators could remain better oriented as to exactly what changes had been commanded in long term pitch performance. All operators commented on the excellent response and rate at which the system worked. Several flew entire approaches through flare and touchdown using this feature.

Performance displays were well received. All subjects indicated that the flight instrument group was the feature they liked best about the console (Table XII). The only adverse comment concerned the range of operation on the lateral situation indicator (LSI). This instrument, displaying runway heading error, deviation from the runway center and crosstrack rate, operated only within approximately 65 feet of the runway centerline. A close examination of objective performance data

TABLE XII

PREFERRED FEATURE OF REMOTE OPERATOR'S STATION COMMENTS

Question:	What is the one property of the console you liked the best? Why?
Comments:	The instrument displays. It was easy tc crosscheck and assimilate the information. It also provides fairly good rate information.
	General instrument layout. It is easy to scan.
	The instrument grouping. With the performance instruments surrounding the ADI, I found developing an effective crosscheck extremely easy. I especially found the location of the LSI and vertical tape(VVI/abs alt) made flaring quite easy.
	The close instrument display which facilitates a fast crosscheck.

substantiates the fact that there is definitely a control/display problem in the lateral axis. Subject operator comments in the debriefing and experimenter observations during the test substantiate the need for an improved lateral rate display.

The attitude director indicator (ADI) installed for this test displays glideslope deviation and flight path angle information on the left side of the sphere, while the vertical velocity and absolute altitude displays were mounted to the right of the ADI. The subjects were extremely unhappy with regards to this separation of pitch information.

The absolute altitude display in the one-inch module was criticized severely. The subjects considered the tape too narrow and objected to the tape disappearing toward the center lubber line as the aircraft approached the runway surface. These factors, the subject felt, led to a too subtle indication of closure. This could explain the fact that they sometimes flared late or not at all.

The subjects made it known that tne only course or localizer warning flag available was on the ADI. Thus, primarily when using the HSI, it would be very easy to miss a localizer failure.

Airspeed was automatically controlled on all approaches made in this test. Therefore, operators did not give the same critical examination to all features of the speed control/display arrangement.

The range and range rate displays, most subjects felt, were too far from their center of attention on the approach. Also, the information displayed was felt to be too coarse to complete the landing.

Cueing functions were rated by subjects in regard to providing advance notice of upcoming events in the accomplishment of each maneuver. Generally, they were satisfied with early cues such as those for localizer and glideslope capture and were somewhat dissatisfied with those which occur at lower altitudes as the aircraft approaches touchdown (Table XIII).

In this simulation, the ROs used the television display only at extremely low altitudes and for limited taxi operations. All agreed that TV was usable for ground taxi operations and for alignment during takeoff and landing rollout. It is also noted that lateral control on the ground, even at high speeds, was considered extremely easy.

4.5 STATION MANNING

In response to the question on manning requirements, the subjects were unanimous in that there should be no less than two persons at the console. Operators were primarily interested in having a second operator/engineer available to monitor system operation and handle communication tasks (Table XIV). In most cases, these opinions are an expression of past experience in actual RPV operations in an operator/supervisor capacity. These comments are also an expression of their experience in this simulation program that the approach requires a workload which precludes the taking on additional burdens (systems monitoring, data link operation, etc.).

TABLE XIII

CUEING FUNCTION COMMENTS

<u>Cueing Functions</u> - Subjects rated the displays in regard to providing advance notice of upcoming events for each maneuver on the approach, landing and for missed approach. Averages for the go-around (missed approach) reflect ratings of only two subjects.

(1) Localizer Capture

Unsuitable		Suitable	Highly Suitable	
1	2	3	4	5

↑ 4.0

Untimely		Timely	Very Timely	
1	2	3	4	5

↑ 3.75

(2) Glideslope Capture

Unsuitable		Suitable	Highly Suitable	
1	2	3	4	5

↑ 4.5

Untimely		Timely	Very Timely	
1	2	3	4	5

↑ 4.25

(3) Alignment

Unsuitable		Suitable		Highly Suitable
1	2	3	4	5

↑ 2.0

Untimely		Timely		Very Timely
1	2	3	4	5

↑ 2.25

(4) Flare

Unsuitable		Suitable		Highly Suitable
1	2	3	4	5

↑ 2.0

Untimely		Timely		Very Timely
1	2	3	4	5

↑ 2.5

(5) Touchdown

Unsuitable		Suitable		Highly Suitable
1	2	3	4	5

↑ 1.5

Untimely		Timely		Very Timely
1	2	3	4	5

↑ 2.0

(6) Rollout

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 2.0

Untimely Timely Very Timely

1 2 3 4 5

↑ 2.25

(7) Go-around

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 2.5

Untimely Timely Very Timely

1 2 3 4 5

↑ 2.5

(8) Failures

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 1.5

Untimely Timely Very Timely

1 2 3 4 5

↑ 2.5

TABLE XIV

ONE-MAN VS. TWO-MAN COMMENTS

ONE-MAN VS. TWO-MAN OPERATION

All operators indicated a need for two operators for a variety of reasons. All comments in regard to this question are listed below.

a. The second man is required to operate the data link system and monitor data link and RPV systems. He could also be of assistance with communications.

b. When three axes failures occur, the idea is not to see how good an RO might be, but to get it on the ground safely. Don't saturate an RO. Besides, with a real RPV there is going to be plenty of work to spread around.

c. I think a second man is required to function as "systems analyst" and radio operator. Flying a manual approach requires too much attention to monitor engine instruments, make radio calls, etc.

d. At low altitudes, during the nitty-gritty portion of the approach, I don't have time to monitor the system operation. In fact, I might use him to manually align for me on a three axes failure, radio calls. Emergency procedures. A training area for new ROs.

5. INTERACTION OF REMOTE CONTROL AND AUTOMATIC CONTROL

This issue addresses the interaction of remote control in the failed axes with the ALS and its performance in the remaining, unfailed axes. Two comparisons are made, remote longitudinal control and its effect on ALS lateral control, and remote lateral control and its effect on ALS longitudinal control.

5.1 REMOTE LONGITUDINAL AND ALS LATERAL

Lateral performance at TD is presented for both remote pitch modes, proportional pitch attitude and flight path angle, and for the ALS. The lateral parameters of interest are bank angle (ϕ), heading error (ψ_ε) which is equal to runway course minus aircraft heading, lateral dispersion (y) and crosstrack rate (y). The median and range scores for these parameters are shown in Table XV.

Bank angle at TD should, by design, be zero for the ALS. Remember also that the crosswinds were always from the left and left wing down (negative ϕ) attitudes are to be expected. The medians show nearly wings level in both ALS and proportional pitch. Flight path angle shows a slightly lower left wing attitude; however, all are well within acceptable limits. The bank angle range scores show, however, that precision, or repeatability, is reduced with the remote control modes.

Heading error, when under ALS control, was programmed to drive to zero at TD. Once again, the median values show a slight difference while the range scores of heading error reflect high variability in

terms of precision. What appears from the data is that while precision remains marginal, overall performance improves slightly with the remote pitch modes.

Lateral displacement for the ALS was supposed to be zero (on centerline). The median values of Table XV shows ALS and both remote pitch modes as essentially equal and acceptable. The tendency was to land right of centerline (positive value) which is as expected for a left crosswind. The lateral displacement range values, however, show reduced precision for both remote pitch modes with flight path angle being worse.

Crosstrack rate is designed to be minimized by the ALS. The median data show an ALS score of zero (ideal) with a tight range indicating consistent performance. The remote effect on this, however, is an increase in crosstrack rate median scores, although they are still in the acceptable region of the TD criteria. The range values of crosstrack rate increase significantly for crosstrack rate as they do for lateral dispersion.

5.2 REMOTE LATERAL AND ALS LONGITUDINAL

Two longitudinal parameters are used to assess the interaction. They are vertical velocity ($\dot{h}$) and longitudinal dispersion (x). The median and range scores for these parameters are shown in Table XVI.

TABLE XV

BANK ANGLE, HEADING ERROR, LATERAL DISPLACEMENT, AND CROSS-TRACK RATE AT TOUCHDOWN FOR REMOTE VS AUTOMATIC CONTROL

PARAMETERS	CONTROL MODE		
	AUTO	PROP. PITCH	FLT. PATH ANGLE
BANK ANGLE-deg.(θ)	-.5(1.5)	-.5(6.6)	-1.5(6.1)
HEADING ERROR-deg.(Ψ_ε)	-2(7.1)	-1.5(5.1)	-.5(8.2)
LATERAL DISP.-ft.(y)	15(11)	14(44)	17(119)
CROSSTRACK RATE-fps($\dot{y}$)	0(1.5)	.8(5.1)	1.3(16.9)

TABLE XVI

VERTICAL VELOCITY AND LONGITUDINAL DISPERSION AT TOUCHDOWN FOR REMOTE VS AUTOMATIC CONTROL

PARAMETERS	CONTROL MODE			
	AUTO	PROP. ROLL	PROP. YAW	PROP. ROLL&YAW
VERTICAL VELOCITY-fps($\dot{h}$)	2.5(3.2)	2.8(3.1)	2.4(3.5)	2.4(2.6)
LONGITUDINAL DISP.-ft.(x)	445(918)	796(2949)	846(1923)	410(2487)

Vertical velocity is designed to attain 2.5 fps at TD by the ALS. As the data show, there is essentially no difference between ALS or remote control in either the median or range scores for this parameter.

Longitudinal dispersion was measured in feet. The ALS was designed to land with dispersion not to exceed ±500 ft. The data of Table XVI show both the ALS and the manual roll/yaw mode to have medians within this area. The single axis modes indicate a tendency for the ALS to land long when they are used. All remote combinations increase the variability significantly with single axis roll having the most impact, indicating an obvious level of adverse interaction between the axis and the ALS longitudinal control.

SECTION IV

CONCLUSIONS

1. Conclusions regarding each of the simulation test program objectives are presented in this section. In retrospect, the simulation set up and procedures were sufficiently accurate and repeatable to collect the needed data and to draw meaningful conclusions. The simulation results, however, were not intended and should not be used to establish the accuracy with which a remote operator may accomplish operational RPV instrument approaches and landings in adverse weather.

2. Supervisory override mode - As implemented, the supervisory override (SO) mode is useful only during localizer and glide slope capture phases of the landing sequence; it does not enable an RO to aid the automatic system to improve approach and landing accuracy.

3. Preferred remote control modes

a. Proportional flight path angle with trim is the preferred pitch axis remote control mode. The ROs were unanimous in their preference for this mode and the objective data support their choice.

b. Proportional bank attitude is the preferred roll axis remote control mode. Significant improvement in roll axis control is required, however, because the ROs consider their workload too high, vehicle response poor and touchdown accuracy unacceptable.

c. Proportional yaw rate with heading hold is an acceptable yaw axis remote control mode for the control functions investigated.

d. Proportional pitch rate and roll rate are not acceptable remote control modes for approach and landing. In general, the RO's workload (with these modes) is unacceptably high and their ability to control the vehicle, its path and touchdown unacceptably poor.

4. Remote Operator's Role in Degraded Control Conditions

a. A remote operator is faced with a difficult task when recovering an RPV on instruments in turbulent and gusting conditions. Generally, when required to control more than a single RPV attitude axis, the probability of a satisfactory landing is unacceptably low.

b. Interaction between remote control in one axis and automatic control in the other axes was significant with the selected mechanization. Often, this interaction adversely affected the operation of the automatic control system and degraded approach and touchdown performance.

5. Control/Display Suitability

a. The control/display complement is adequate for system initialization, path monitoring, first AFCS failure annunciation and remote control to flare initiate (approx 50 ft) altitude.

b. The control/display complement is inadequate for:

(1) AFCS mode change/approach sequence annunciation

(2) Runway threshold crossing indication

(3) Runway remaining indication

(4) Multiple AFCS failure annunciation

(5) Remote control through flare and touchdown

c. Side arm controllers are acceptable for elevator, aileron, rudder, spoiler and throttle control.

d. The location, angle, and dead-band of the primary flight controller are unacceptable.

e. The TV, by itself, is inadequate for any RO control function in IFR. In VFR, the TV was considered useful for:

(1) Last phase of rollout and taxi

(2) Increased confidence of a satisfactory approach than possible with the basic instrument panel only

(3) A more rapid control establishment and instrument orientation following an approach upset or instrument disorientation

f. Neither the decrab or side-slip are acceptable remotely controlled runway alignment techniques.

g. A two-man recovery team is <u>required</u> in those cases where the ROs need to control the RPV in more than one axis and <u>desirable</u> in single axis control cases.

SECTION V

RECOMMENDATIONS

1. Recommendations regarding each of the simulation test program objectives are presented in this section. As a preface to these, it is recommended that work be continued to develop an effective interface between the human operator and the vehicle. In light of the limited success the ROs had in this program, it is suggested that the RO's interface with the vehicle be based on advanced man/machine concepts and he not be tied to the classical pilot/airplane role.

2. Remote Control Modes

a. A remote control mode with the stated advantages of the conceptual supervisory override mode should be developed. This mode should not require the RO to change system operating modes, configuration or his thought process; the RO should have instant access to a control situation he has been monitoring and is fully familiar with. Possibly, rather than summing the RO's inputs with the autoland input to the inner loop, they could modify the glide slope or localizer signals, internal computer gain, or a time constant.

b. As part of any development to implement the control modes used in this simulation, sufficient handling qualities work should be accomplished to obtain satisfactory vehicle control precision, response and RO acceptance.

c. An improved remote roll control mode should be developed. Proportional roll, while preferred, does not yield acceptable vehicle control, approach precision or touchdown accuracy.

d. An improved remote runway alignment technique is required if a human operator is required to accomplish this task. The techniques investigated did not enable sufficiently precise touchdown and vehicle cross track velocity control.

3. Remote Operator's Role In Degraded Control Conditions

a. The RPV's primary approach and landing mode should be fully automatic with adequate reliability to preclude a need by the RO to control more than one axis. With the existing displays and controls, the RO's capabilities are limited and the probability of successful, fully remotely controlled instrument recoveries is low.

b. If an RO is required to recover the RPV on instrument, his problem may be eased significantly if the flare and decrab maneuvers could be eliminated. Also, use of direct side force could enhance the RO's capability. These possibilities should be considered as part of an RPV recovery system design trades study.

4. Control/Display Suitability

a. Additional human factors engineering should be accomplished to overcome the noted inadequacies of the control/display complement.

APPENDIX A

REMOTE OPERATOR'S STATION (ROS)

The ROS is designed for two-men, seated side-by-side, and consists of five modular units and two pie-shaped sections to form a wrap-around console (Figure A-1). Writing surfaces are provided for each operator along with sloping surfaces to serve as mounts for the flight controllers.

The primary operator is located on the right, to allow use of a side-arm controller and give both operators access to controls and displays located in the center of the console. Center and left hand panels contain subsystem controls and displays for the second operator. The other panels and the sloping surfaces contain flight system controls and displays for the RO. Figures A-2 and A-3 show reach and vision envelopes for the RO when seated at the ROS. The controls and displays on each panel are described in the following sections.

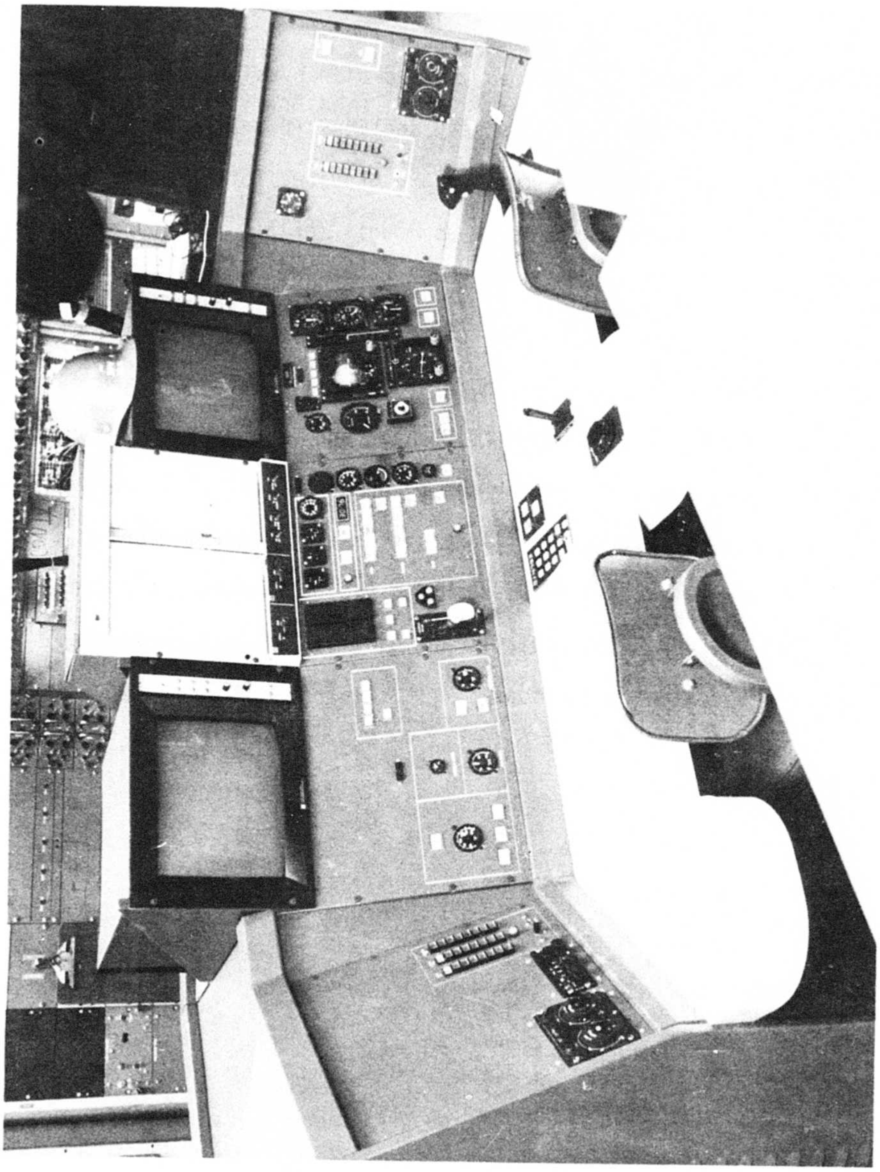


Figure A-1. Remote Operator's Station

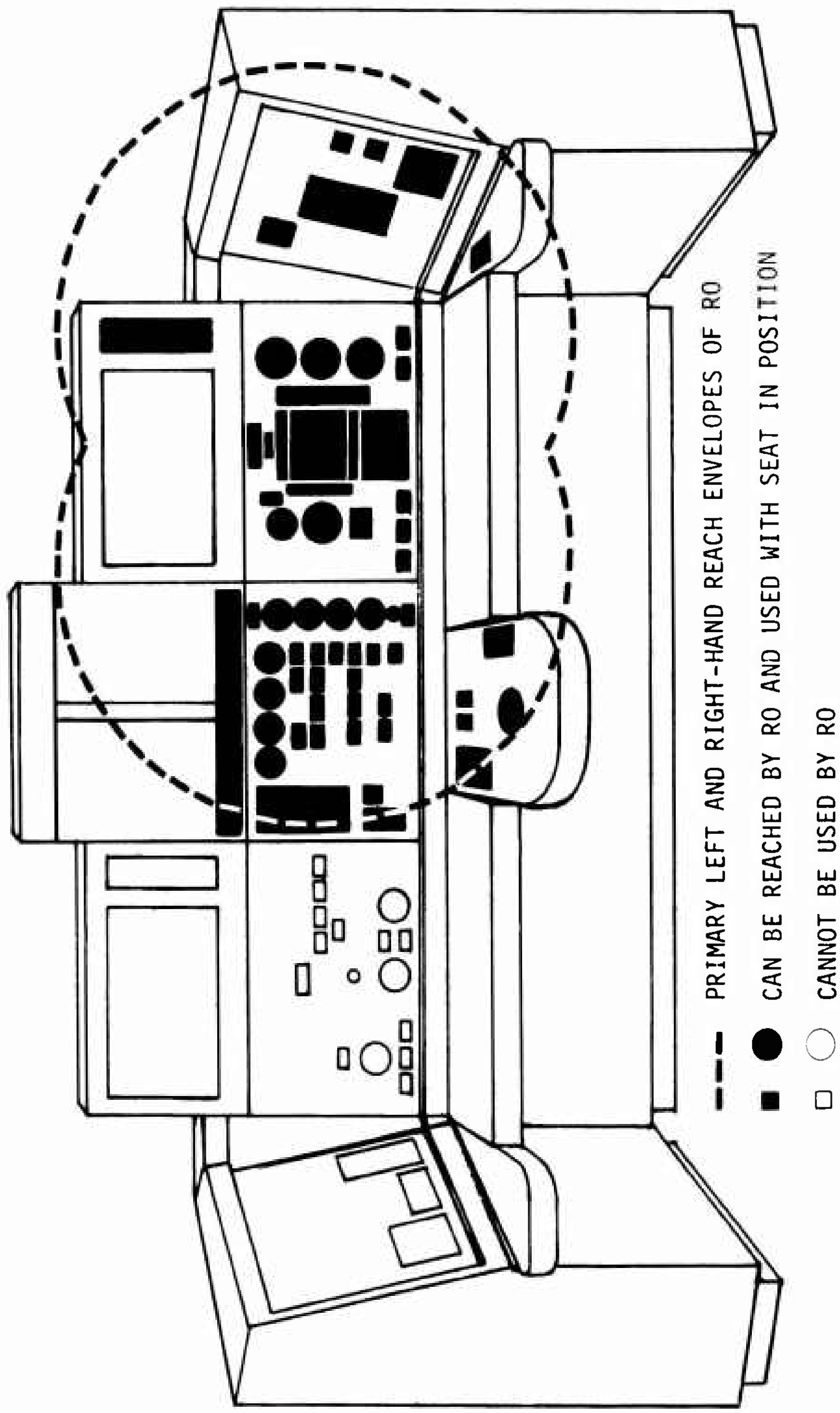


Figure A-2. Reach Envelope

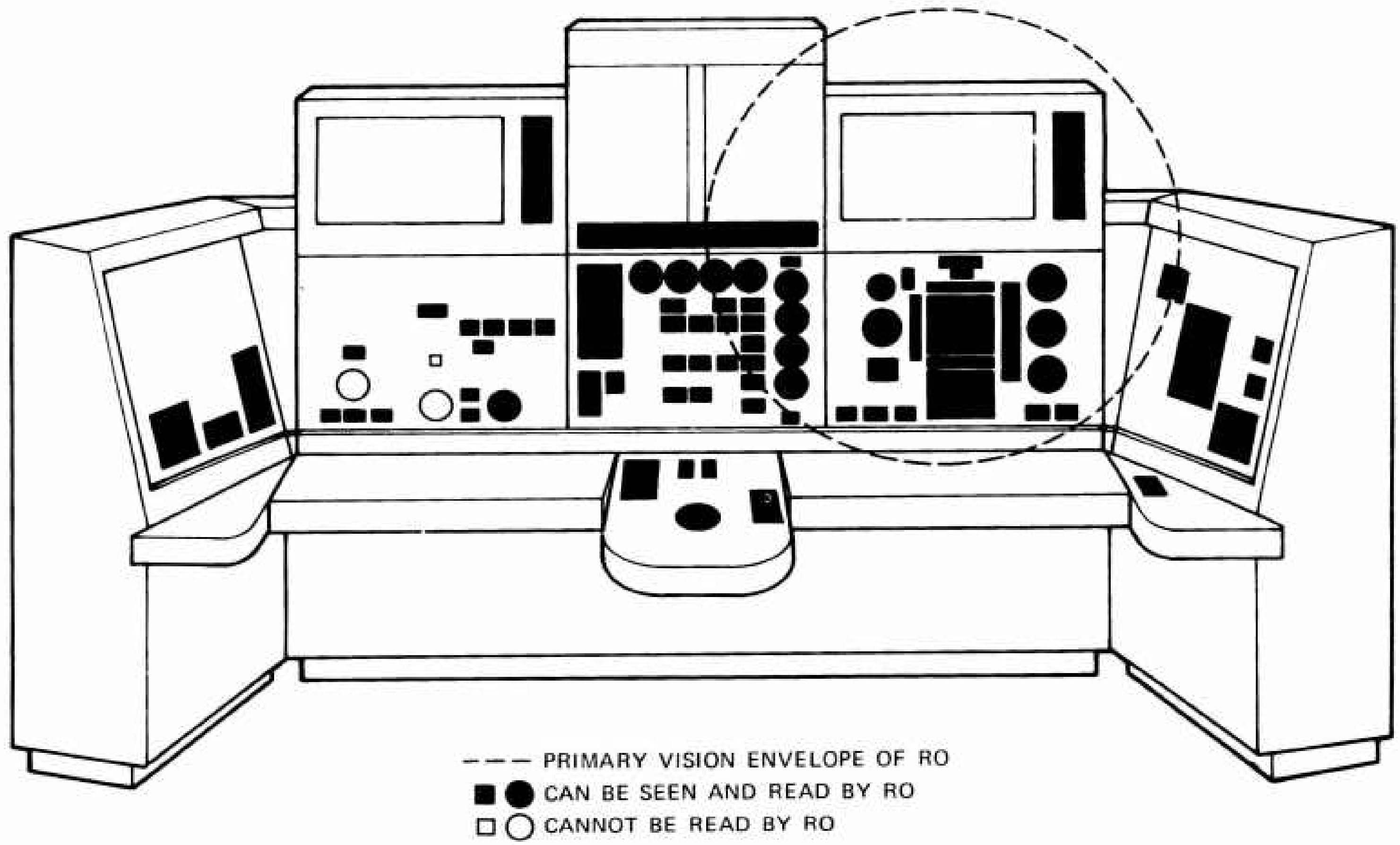


Figure A-3. Vision Envelope

Subsystem Monitoring Panel (Figure A-4)

(1) Communication Control: This push-button arrangement is designed to provide intercom switching for the second operator.

(2) MLS Control Head: Inoperative and installed only to simulate a control required for actual RPV operations.

(3) ROS Lighting Control: This standard control head adjusts the intensity of the instrument lights on system monitoring panels.

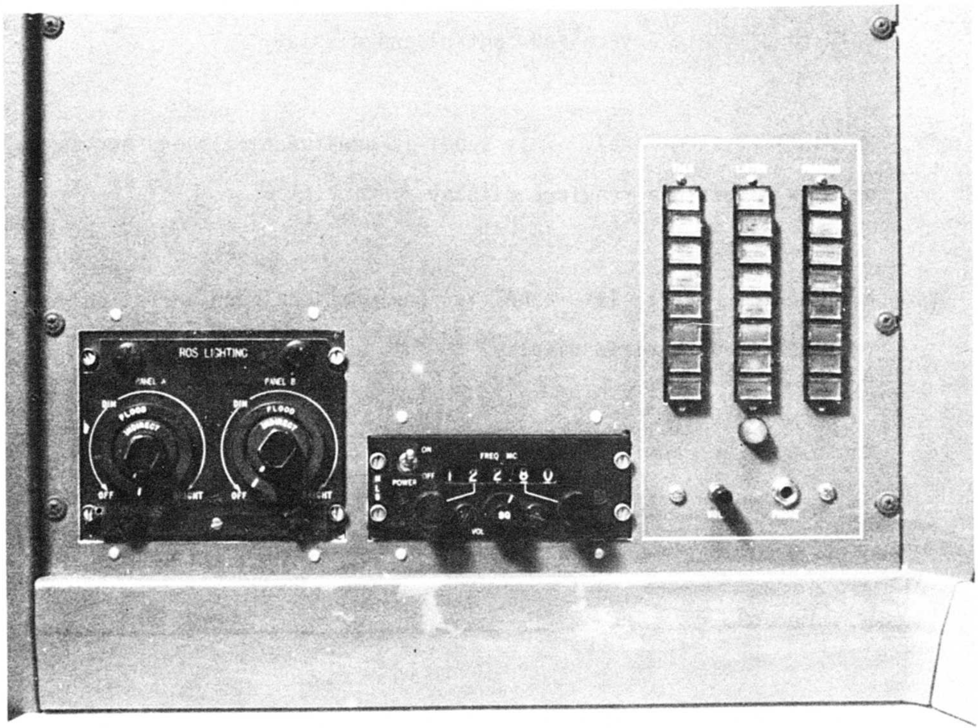


Figure A-4. Subsystems Monitoring Panel

RPV System Monitoring Panel (Figure A-5)

(1) Master Caution Light: This light would normally illuminate anytime a light on the caution/warning panel would illuminate. In this installation, however, it was connected only to the "stall" and "throttle off" lights.

(2) Stick Input Lights: These lights serve to indicate when an input signal from any of the controllers is being sent.

(3) Electrical System Panel: The panel is non-functional and serves only to simulate a required control and display.

(4) Hydraulic System Panel: This panel is non-functional and serves only to simulate a required display.

(5) Fuel System Panel: This panel is non-functional and serves only to simulate a required display.

(6) Console Power Panel: This panel provides ROS' power switching and monitoring. The power switches are functional.

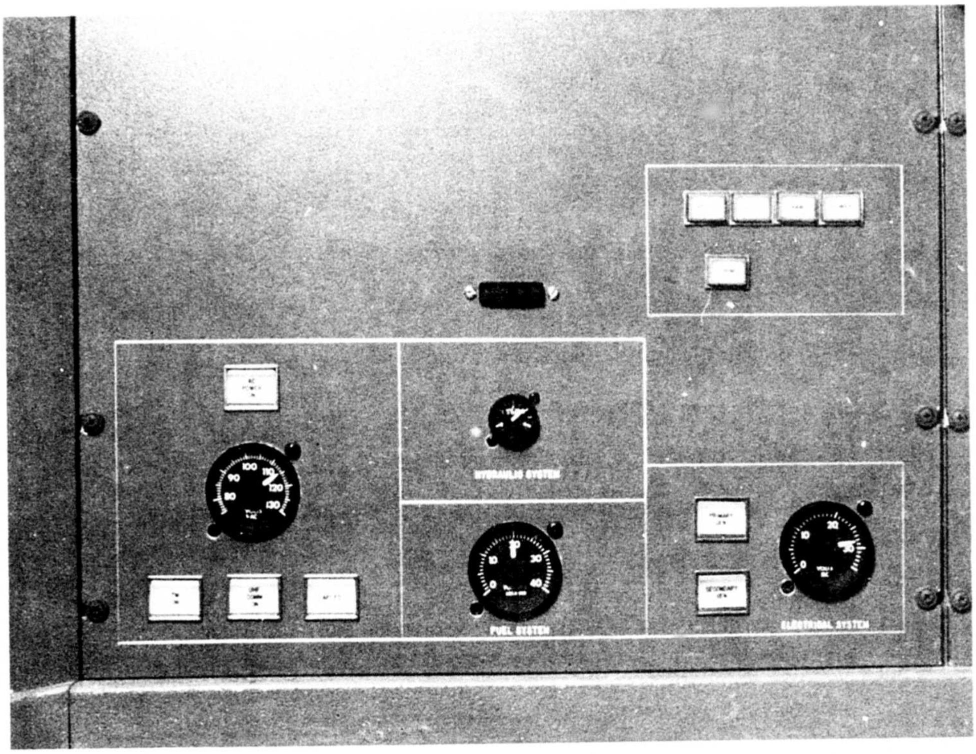


Figure A-5. RPV Systems Monitoring Panel

AFSC Monitoring Panel (Figure A-6)

(1) Caution/Warning Panel: Only the "throttle off" and "stall" warning lights are operative. Others are included to simulate a typical RPV warning system.

(2) Control Surface Indicators: These display the position of the RPV rudder(s), ailerons, elevator and spoilers.

(3) Fire Warning Light: Non-functional simulation.

(4) Engine Instruments: The RPM display is functional. Fuel flow, EGT and oil pressure are driven as a function of RPM and simulate typical displays.

(5) RPV Identification Display: This simulates a display of RPV information essential for multiple-vehicle operation.

(6) ROS/Mission Control Switches: These switches simulate those required in exchange of control of the RPV between two control agencies.

(7) AFSC Panel: This panel contains switches to couple/uncouple the individual AFSC axes.

(8) Landing Gear Control: This control simulates a conventional landing gear handle.

(9) Gear Position Lights: These lights indicate gear "down and locked."

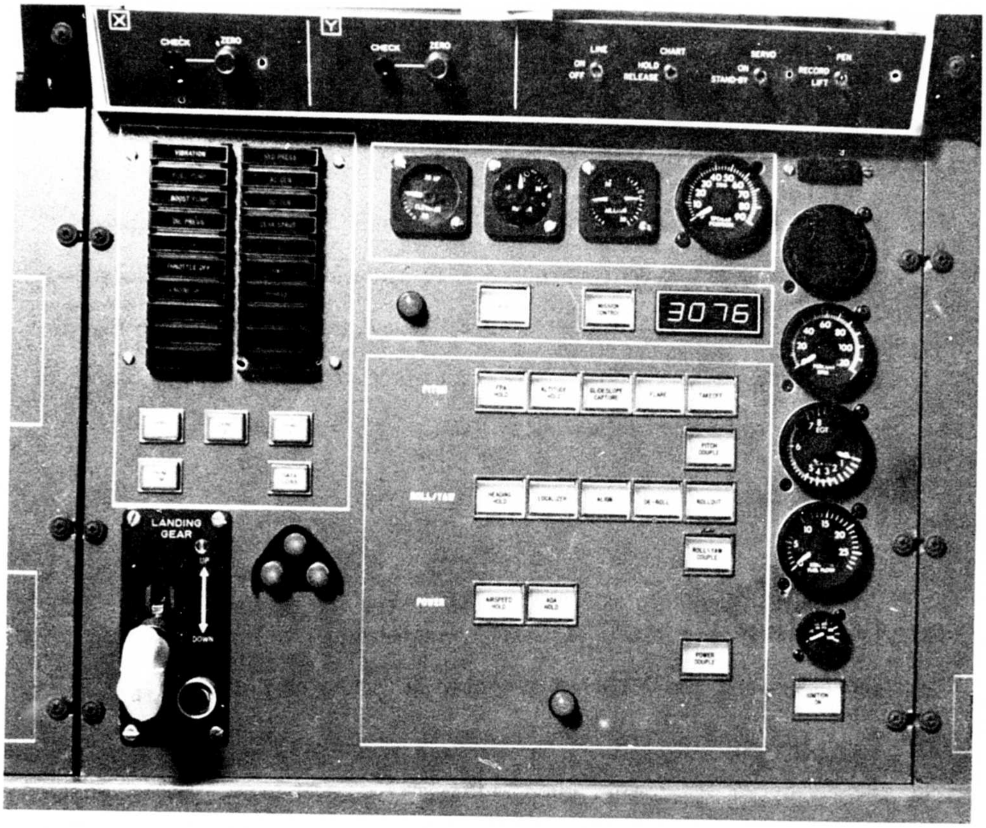


Figure A-6. AFCS Monitoring Panel

Flight Instrument Panel (Figure A-7)

(1) Angle of Attack Indicator: This display presents RPV angle of attack information to the RO.

(2) Attitude Indicator: This display is essentially a "cleaned up" version of the standard ARU/2B instrument. It has a blue/brown color coded attitude sphere and a flight path angle on left edge. The flight path angle tape display ± 30 degrees of path angle with respect to level flight. Signals used to compute FPA are indicated airspeed and vertical velocity (VV). The VV computation is described in (11) below.

(3) Go-Around Light: This light illuminates when the abort switch is depressed and the AFCS has switched into the go-around mode.

(4) Ground Speed Indicator: Operative only on the ground, this indicator displays ground speed in knots.

(5) Master Caution Light: This light illuminates to attract attention to the caution/warning panel. The light can be reset by depressing it.

(6) Takeoff Abort Light: This light illuminates when the ABORT switch is depressed and the AFCS has switched into the ABORT mode.

(7) Approach Sequence Indicator: Individual segments of this indicator illuminate when mode switching conditions have been met. Modes on the display are Localizer Capture, Glideslope Capture, Align (150' AGL), Flare (70' AGL), Deroll (5' AGL), Touchdown (main gear) and Rollout (nose gear).

(8) Range/Range Rate Indicator

(9) Radar Altitude

(10) Barometric Altitude

(11) Absolute Altitude/Vertical Velocity Indicator (AVVI): This instrument displays absolute altitude from approximately 1000 feet AGL to the surface. The display is calibrated to show the final fifty feet of altitude in approximately 1-1/4 inches of tape movement. The vertical velocity display consists of barometric altitude rate, acceleration and washed out pitch signal. At absolute altitudes below 150 feet, radar altitude rate is used in place of the augmented barometric rate.

(12) Loss Track Light: This light on the radar altitude indicator illuminates to indicate loss of a valid radar altimeter lock.

(13) Horizontal Situation Indicator (HSI): This is a standard AQU-2/A indicator.

(14) Lateral Situation Indicator (LSI): This instrument displays heading error, lateral deviation from the MLS localizer course and crosstrack rate. The runway symbol on the LSI is calibrated to display a 125 foot runway width throughout the approach. Localizer deviation and range are used in this computation.

(15) Destruct Arm, Destruct Switches: These are non-functional simulations.

(16) Glideslope Angle Selector: Non-functional, this selector simulates a required control.

(17) Command Airspeed Selector: This control was functional and establishes the approach speed reference for the autothrottle system.

(18) Speed Error/Speed Error Rate Indicator: This indicator displays deviation and rate of speed change from that selected.

(19) Airspeed Indicator: Displays RPV airspeed.

(20) Stall Indicator Light

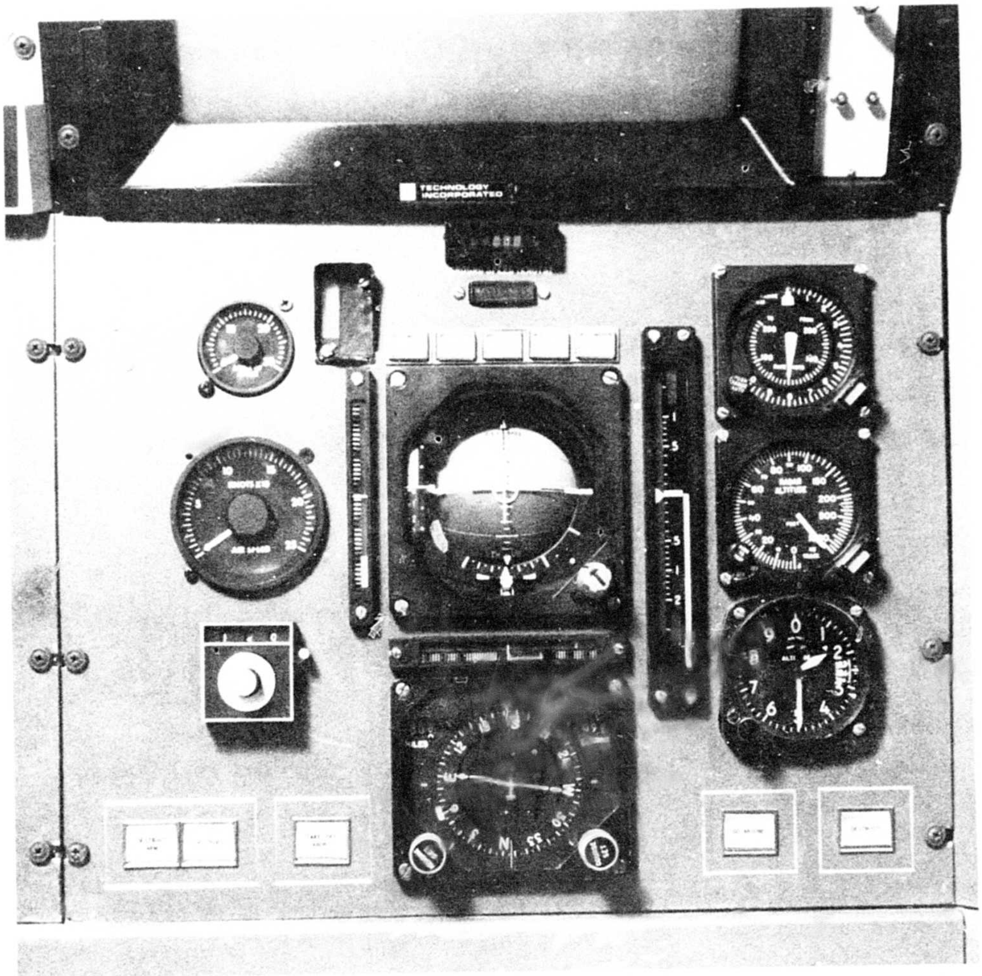


Figure A-7. Flight Instrument Panel

Miscellaneous System Panel and Flight Controller Panel (Figure A-8)

(1) RPV Build-in Test Equipment (BITE) Switch: Non-functional simulation of a required feature.

(2) ROS Bite Switch: This switch is used to test all lights on the ROS.

(3) ROS Lighting Control: This standard control is used to adjust intensity of the instrument lights.

(4) Clock: A standard eight-day, wind-up clock.

(5) Communication Control: This push-button arrangement provides intercom switching for the RO.

(6) Control Stick: This controller provides pitch and roll commands to the RPV flight control system.

(7) Brake: This switch, when depressed, brakes the RPV.

(8) Microphone Switch: This standard microphone pushbutton is located on the stick.

(9) Trim Switch: This standard five position switch is used to trim the pitch and yaw axes of the AFSC. Momentary activation commands 1/2 degree pitch change; holding the switch commands a pitch rate of one degree per second. Momentary left or right movement of the trim switch commands yaw angle changes of one degree; holding the switch commands a yaw rate of two degrees per second.

(10) Abort Switch: The switch initiates the takeoff abort or go-around maneuver as a function of mode selection.

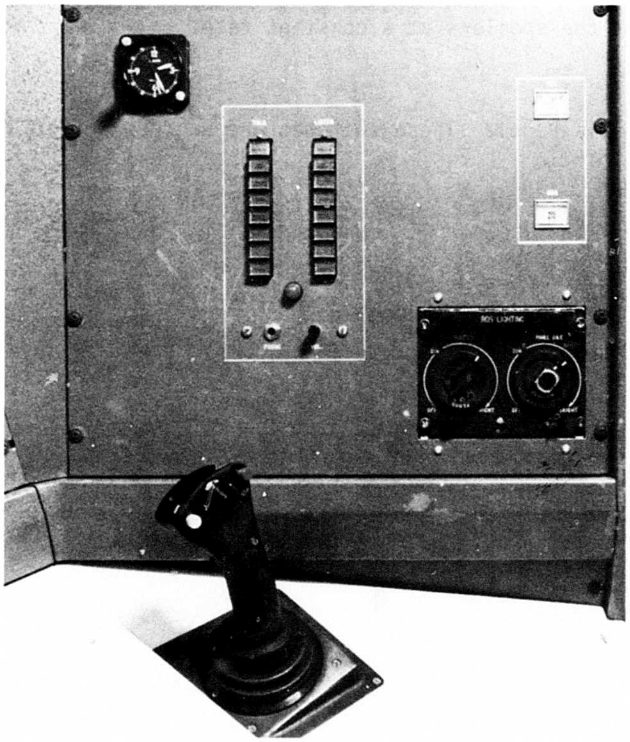


Figure A-8. Miscellaneous System Panel and Side Stick Controller

Center Console Panel (Figure A-9)

(1) Keyboard: This non-functional control simulates the capability of entering communication frequencies and RPV identification codes.

(2) Yaw Controller: This controller is used to command RPV heading changes.

(3) Throttle: This controller is used to command RPV power changes.

(4) Spoiler Control: This sliding thumbswitch is used to extend or retract the spoilers at a constant rate.

(5) ALS Enable Panel: These switches are used to select ALS operating modes.

Figure A-9. Center Console Panel

APPENDIX B

SUBJECT BACKGROUND DATA

The successful completion of a simulation effort depends, to a large degree, on the subjects. Their ability to relate to the total problem and their flying skills directly affect the ROS assessment. With this in mind, the RPV SPO (ASD/YW) provided subjects whose skills and background included:

a. An RPV orinetation - the subjects were familiar with RPVs which included actual RPV flying experience.

b. An instrument orientation - the subjects were currently IFR rated and intimately familiar with landing operations.

c. A research attitude - The subjects had a research experience background which contributed to the feedback loop.

d. Some were IFC graduates.

e. The subjects were familiar with the use of flight director.

Table B-1 is a summary of Pre-Simulation Questionnaire responses and indicates the broad background and experience of the test subjects.

TABLE B-1

PRE-SIMULATION QUESTIONNAIRE RESPONSES

1. Test subject flight qualifications:

   Aircraft commander
   Test pilot
   Instructor pilot
   Instructor drone recovery officer
   Standards evaluation pilot
   Navigator/Electronic Warfare Officer
   FAA commercial license

2. Test subject flight experience:

A/C Type	Pilot Time	Instrument Time	Simulator Time
T-41	40		
T-37	170		20
T-38	330		30
T-33	350		
T-39	400		
T-28D	40		
T-1A	75		
C-130A	1170	150	225
C-130B	850	75	125
C-130E	2250	275	265
C-130H	850	75	125
C-123	200		
H-19	1500		
H-34	200		
H-53	80		
UH-1B	125		
UH-D	125		
UH-F	125		
UH-N	125		
Single Eng. Recip.	670	10	50
Dual Eng. Recip.	30	5	10
Single Eng. Jet	100	5	10
Dual Eng. Jet	500	10	80

3. Aircraft in which test subjects were current:

   T-33
   DC-130A/E
   HC-130H
   Cessna 172

4. Previous RPV experience of test subjects.

Type	Length	Nature of Experience
BQM, AQM	2 years	Hq AFLC Drone/RPV
CQM, PQM		System Control Officer
AQM-H/L	4 months	Launch Control Officer
BQM-34C	2 hours	Flew RPV/Maverick Sim. at WPAFB
AQM-34J		Drone Recovery Officer
AQM-34L		Drone Recovery Officer
AQM-34M		Drone Recovery Officer
AQM-34R		Drone Recovery Officer
Compass Cope	5 hours	Observed Cope flights at Edwards AFB

APPENDIX C

EXPERIMENTAL BLOCK DESIGN

The Study was devoted essentially to system checkout and, while a structured design was generated, the presentation order was not adhered to. Basically, the Study was a 16 x 2 x 2 complete block design (see Fig. C-1). The pilots experienced all alternative RO control modes under single, dual, and triple axes failure combinations for the approach and landing. Additionally, the single axis conditions were investigated for takeoff (pitch or roll) and taxiing (yaw or power).

The Pre-Test consisted of three easily distinguishable parts: familiarization, training, and data collection. The familiarization was a 4 x 1 x 4 complete block design (see Fig. C-2). The training was an 11 x 2 x 4 complete block design (Fig. C-3) presented so that training on each axis failure/control mode immediately preceded the data collection on that combination. This approach was selected to preclude the possibility of interference, or confusion, resulting from the necessity to learn all modes before data collection. The data collection was also completely blocked across subjects and all independent variable levels, with the exception of VMC environmental condition which was restricted to familiarization. Following the training block, all four subjects participated in the data collection on approaches. The design for the data collection was an 11 x 3 x 4 matrix (Fig. C-4).

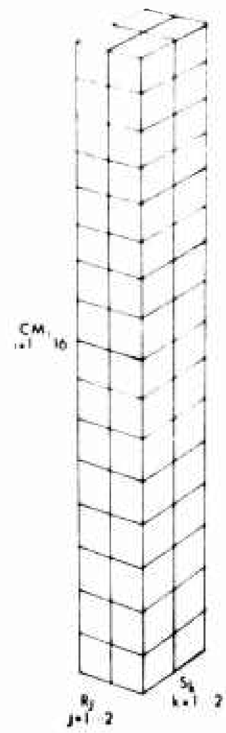


Figure C-1. Study Block Design

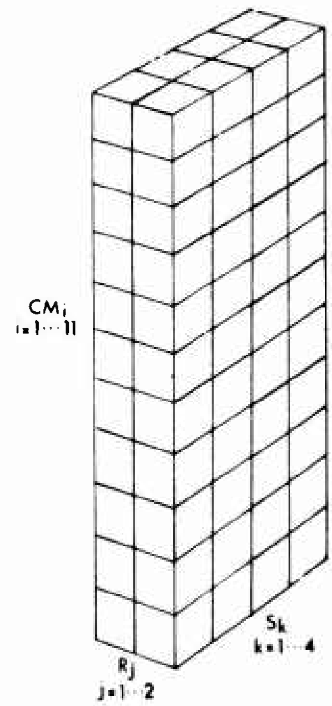


Figure C-3. Pre-Test Training Block Design

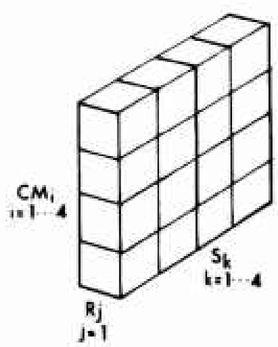


Figure C-2. Pre-Test Familiarization Block Design

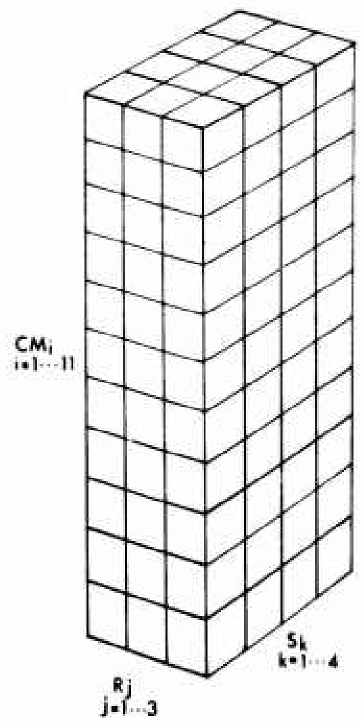


Figure C-4. Pre-Test Data Block Design

For the training/data collection combinations, order presentations of axis failures/control modes were randomized within subjects, with the one constraint that the single-axis failures preceded the three-axis failures.

The Test portion also had three basic blocks: supplemental training, data collection (approaches), training/data collection (takeoffs). The supplemental training was included to allow for additional training on the remaining control modes (proportional attitude without flight director and proportional flight path angle), as some control system adjustments were necessary after Pre-Test. This training was of the completely randomized block design type and consisted of a 4 x 5 x 4 and a 7 x 4 x 4 matrix (see Figs. C-5, C-6). Category IIIb visibility was used throughout the training; however, both turbulent and non-turbulent wind conditions were used. The data collection following this training was, likewise, structured as a completely randomized block, consisting of a 4 x 5 x 4 and a 7 x 2 x 4 array (Figs. C-7, C-8). The takeoff training and data collection blocks were identical and consisted of a 4 x 2 x 2 completely randomized block (see Fig. C-9). The takeoff portion of the Test consisted of only single axis failures, which were part of the initial conditions. All portions of the Test, unless otherwise stated, were Category IIIb with turbulence and wind shears.

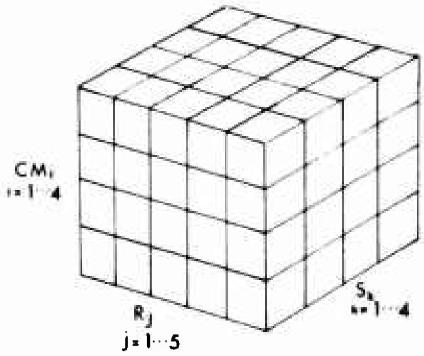


Figure C-5. Test Training (Part 1) Block Design

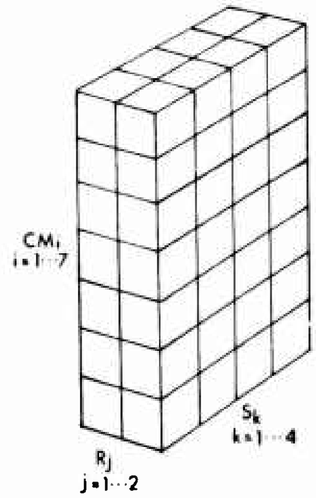


Figure C-8. Test Data (Part 2) Block Design

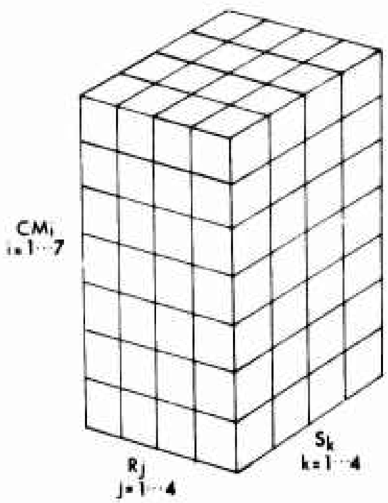


Figure C-6. Test Training (Part 2) Block Design

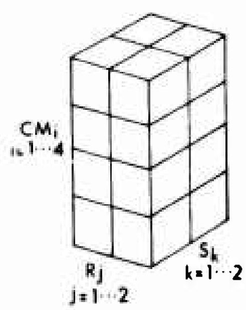


Figure C-9. Test Data (Takeoff) Block Design

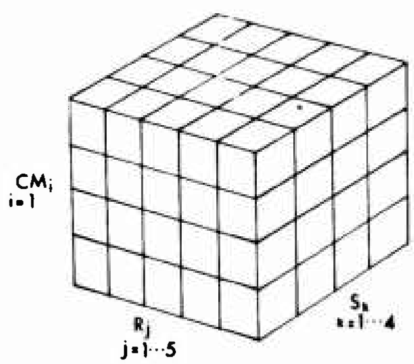


Figure C-7. Test Data (Part 1) Block Design

APPENDIX D

DISCUSSION OF RESULTS

All Data pertinent to some of the simulation issues were not presented earlier. This data is presented here as further substantiation and explanation of the conclusions and recommendations.

RO PERFORMANCE USING SO

All data pertinent to this issue are presented in the Results Section.

RO PERFORMANCE USING REMOTE CONTROL MODES

As a reflection on the inadequacy of RO proportional pitch attitude control with flight director mode, the subjects rated it next to last (Table D-1). The subjects further commented that a flight director of this type (presenting pitch rate commands) provides them little in the way of useful information for controlling the RPV.

The subjects are equally unfavorable towards the proportional rate mode. In their opinion, workload with the rate mode is higher than required for any other mode and, no matter how hard they work, performance does not increase. It may be postulated that the lack of normal visual, aural, and tactile cues prevent the ROs from determing when they have generated an acceptable rate; in any event, they can not make satisfactory corrections with any degree of consistency. Further detailed studies are needed to determine the reasons for the differences between the rate mode and the others.

TABLE D-1

REMOTE CONTROL PREFERENCE COMMENTS

Subjects were asked to rate the remote control modes in order of preference. Rating are:

CONTROL MODE	RATINGS			
Proportional Attitude w/o FD	3	3	3	2
Proportional Attitude w/FD	2	4	2	4
Proportional Rate	5	5	5	5
Proportional FPA (with roll att)	1	2	1	1
Yaw Rate	4	1	4	3

Note that the flight path angle mode is preferred while rate control is disliked.

The discussion of proportional pitch attitude versus flight path angle is adequately covered in the Results. Some additional data is graphically presented to show discernible, though not significant, differences between these control modes: Figure D-1 compares the modes as a function of range (x) at TD; Figure D-2 compares the modes as a function of vertical velocity ($\dot{h}$) at TD; Figure D-3 compares pitch attitude (θ) at TD for both modes.

RO PERFORMANCE VERSUS FAILURE LEVEL

A trend of somewhat greater involvement by the ROs when flying the three axes case is reflected by success percentages. Further investigation is required to determine the significance of this trend. Figure D-4 and D-5 present graphs of success percentage for failure levels as a function of criteria level.

CONTROL/DISPLAY ADEQUACY

During the Test, several subjects indicated that in the event of a two axes failure, they would elect to remotely control the third axis primarily to preclude a surprise failure late into the approach. Overall, in monitoring the ALS, what the ROs want is consistent and predictable aircraft response as automatic switching occurs. For example, if a significant crab existed, at align there should be a smooth change in aircraft heading toward that of the runway and bank should change to compensate for drift; however, the course deviation indicator on the HSI; the LSI runway symbol and crosstrack rate should remain essentially stationary if the confidence in the ALS is to remain high. If anything

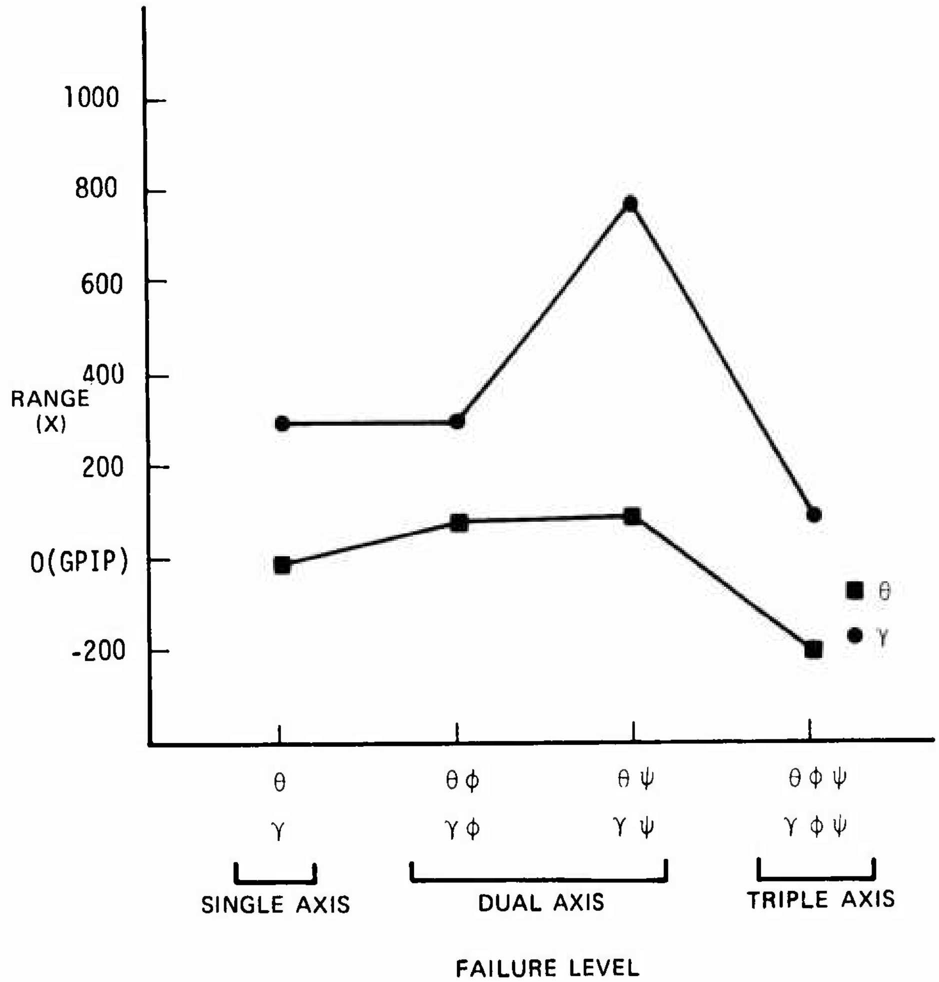


Figure D-1. Range at Touchdown Vs. Failure Level

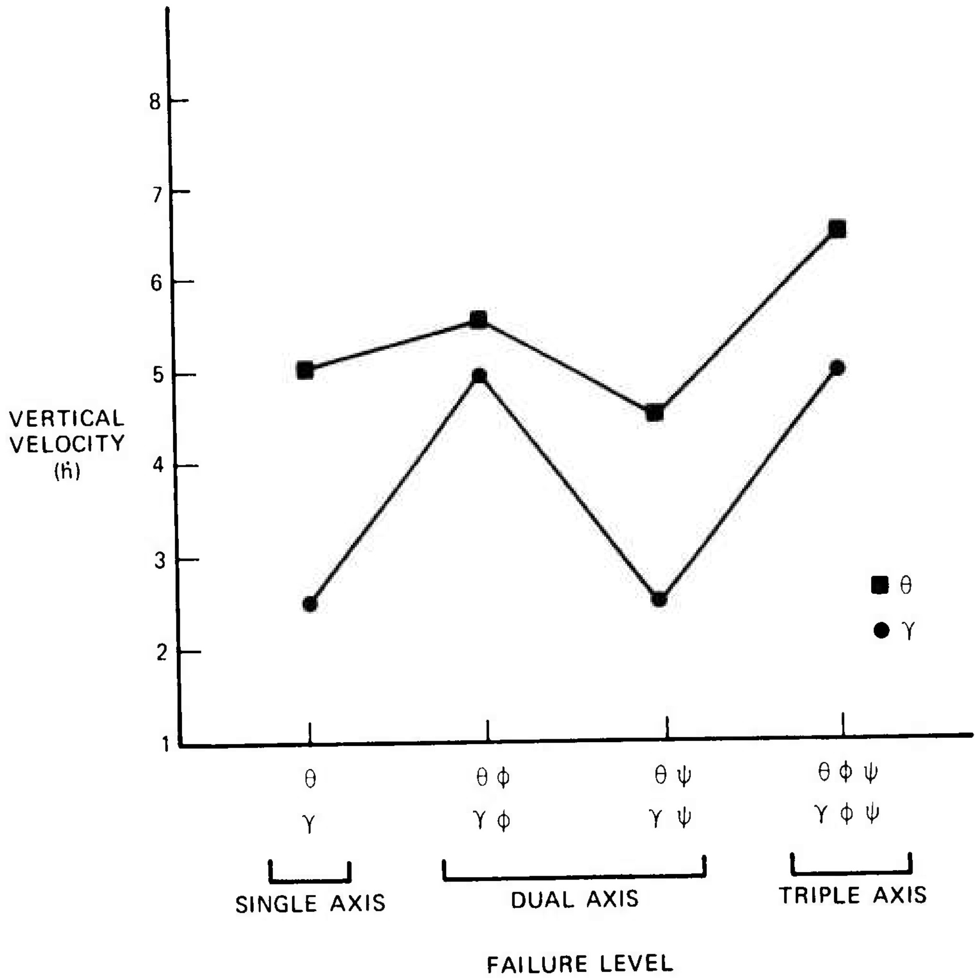


Figure D-2. Vertical Velocity at Touchdown Vs. Failure Level

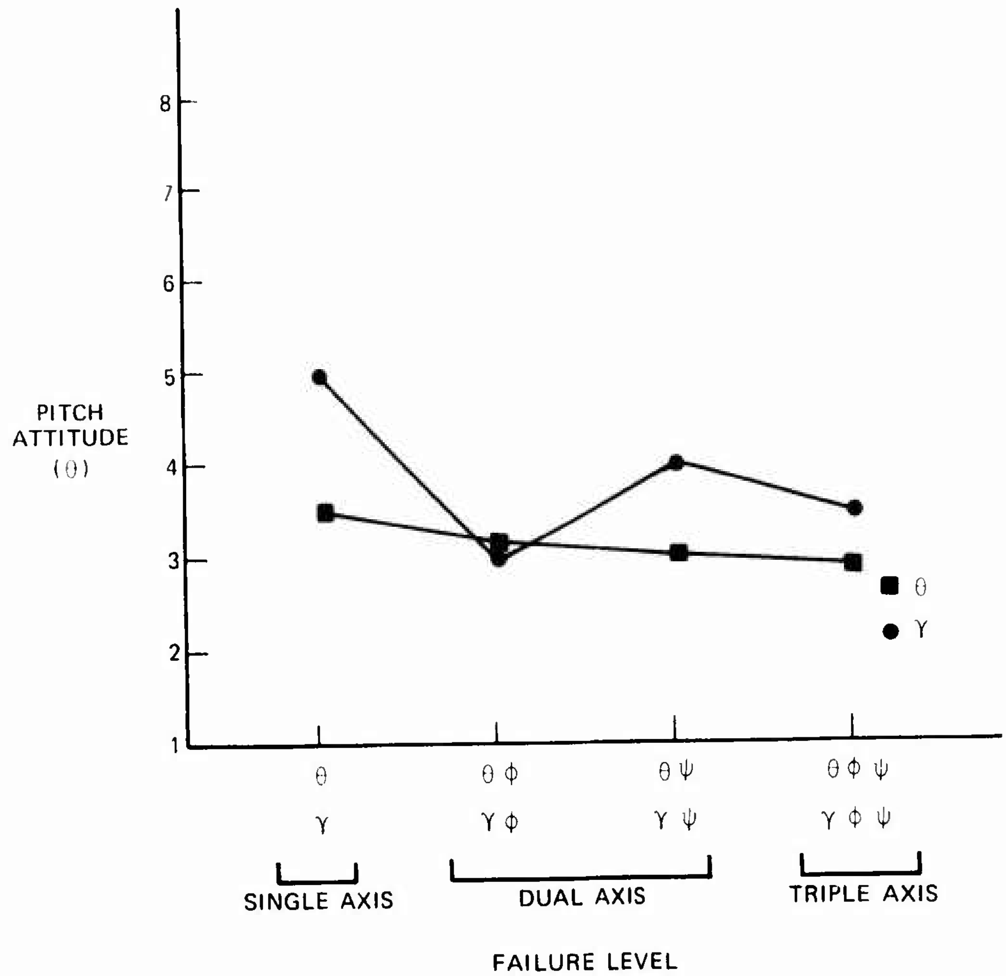


Figure D-3. Pitch Attitude at Touchdown Vs. Failure Level

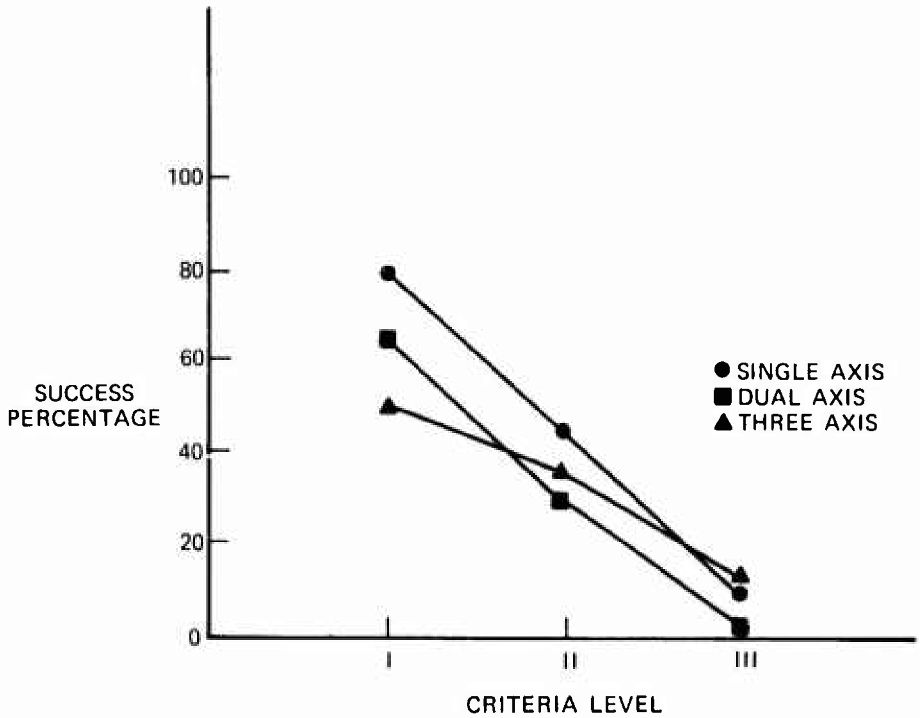
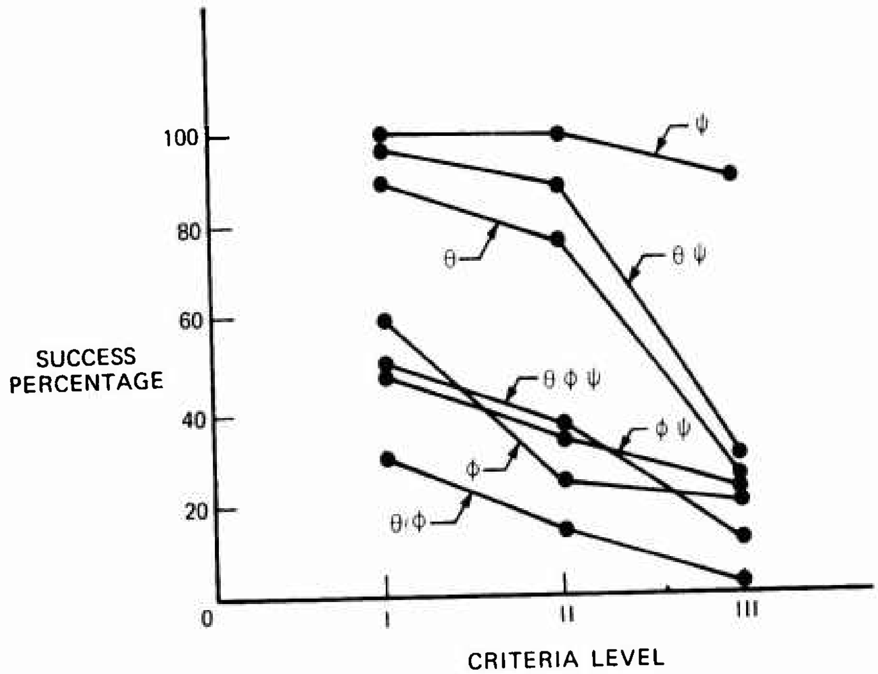


Figure D-4. Single, Dual, Three-Axis Success Percentages Vs. Criteria Level



θ Single axis (prop pitch and FPA)

ϕ Single axis (prop roll)

ψ Single axis (yaw rate)

θϕ Dual axis (prop pitch or FPA and roll)

θψ Dual axis (prop pitch or FPA and yaw rate)

ϕψ Dual axis (prop roll and yaw rate)

ϕψ Triple axis (prop pitch or FPA and roll and yaw rate)

Figure D-5. Failure Level Success Percentages Vs. Criteria Level

unexpected happens, the operator is alerted to an existing or potential malfunction and is geared to take positive and proper corrective action.

INTERACTION OF MANUAL CONTROL WITH AUTOMATIC CONTROL

All data pertinent to this issue is presented in the Results Section.

APPENDIX E

REMOTE OPERATOR POST-SIMULATION QUESTIONNAIRE

A. Remote Operator Station Assessment

1. Operator Opinions

a. Workload - Subjects were asked to rate their workload for varying degrees of RO involvement from single axis control through a fully remote approach. Since power failure was not simulated, one through three axes ratings are used.

Two subjects rated workload for single axis control very low (1), one rated it average (3), and one split the axes by rating yaw very low (1), pitch low (2) and roll high (4). The overall rating for two axes control is somewhat higher with one subject rating it low (2), one average (3) and one high (4). Again, one subject rated yaw control average (3) and pitch or roll control high (4). Three axes control was rated highest with one subject rating it average (3), one high (4) and two very high (5). Average rating for each control condition is:

Very Low — Very High

1 — 2 — 3 — 4 — 5

↑ 1.83 Single Axis

↑ 3.16 2 Axes

↑ 4.25 3 Axes

b. Tracking Task - Subjects rated the tracking task for each remote control mode. The rating scale covered a range from normal (1) to excessive (5).

(1) Two operators rated proportional pitch attitude at 2, while two rated it high (3). In the same range, proportional pitch rate was rated significantly higher with one subject rating it 2, two at 4 and one excessive (5). Proportional flight path angle was rated best with two subjects rating it normal (1) and two at 2. Pitch axis averages are:

Normal High Excessive

1 2 3 4 5

↑ 1.5 Prop FPA

↑ 2.5 Prop Pitch Att

↑ 3.75 Prop Pitch Rate

(2) The roll axis tracking task comparison is between proportional roll attitude and proportional roll rate. One subject rated roll attitude normal (1), two rated it high (3) and one rated it 4. One subject rated roll rate normal (1) and three rated it excessive (5). Roll axis averages are:

Normal High Excessive

1 2 3 4 5

↑ 2.75 roll attitude

↑ 4.0 roll rate

(3) The yaw axis tracking task is rated lowest with three subjects rating it normal (1) and one rating it 2 for a 1.25 average.

Normal High Excessive

1 2 3 4 5

1.25
Yaw

c. Information Displays - Subjects rated the adequacy of the information presented for the various RO functions. Averages for each function, by control mode, are as follows.

(1) Effective system monitoring

Too Little About Right Too Much

1 2 3 4 5

2.5
Prop Rate

3.25
Prop Att
w/o FD

3.0
Prop FPA

3.75
Prop Att
w/FD

(2) Effective Vehicle Control

Too Little About Right Too Much

1 2 3 4 5

1.75
Prop Rate

2.75
Prop
FPA

3.75
Prop Att
w/FD

2.5
Prop Att
w/o FD

(3) Effective Path Monitoring

Too Little — About Right — Too Much

1 — 2 — 3 — 4 — 5

2.5 Prop Rate

3.0 Prop FPA

3.5 Prop Att w/o FD

3.75 Prop Att w/FD

d. Display Format - Subjects rated display format for the same functions described above. Average ratings for each function, by control mode, are as follows:

(1) Effective System Monitoring

Unsuitable — Suitable — Excellent

1 — 2 — 3 — 4 — 5

2.0 Prop Rate

2.75 Prop Att w/o FD

Prop Att w/FD

Prop FPA

(2) Effective Vehicle Control

Unsuitable — Suitable — Excellent

1 — 2 — 3 — 4 — 5

1.75 Prop Rate

2.75 Prop Att w/o FD

3.0 Prop FPA

3.25 Prop Att w/FD

(3) Effective Path Monitoring

Unsuitable   Suitable   Excellent

1   2   3   4   5

2.25 Prop Att w/FD

2.5 Prop Att w/o FD

Prop Rate

2.75 Prop FPA

e. <u>Display Dynamics</u> - Subjects rated display dynamics for the same functions described above. Average ratings for each function, by control mode, are as follows:

(1) Effective System Monitoring

Unsuitable   Suitable   Excellent

1   2   3   4   5

2.33 Prop Att w/FD

2.66 Prop Rate

2.75 Prop Att w/o FD

Prop FPA

(2) Effective Vehicle Control

Unsuitable   Suitable   Excellent

1   2   3   4   5

1.66 Prop Att w/FD

Prop Rate

2.0 Prop Att w/o FD

Prop FPA

(3) Effective Path Monitoring

Unsuitable Suitable Excellent

1 2 3 4 5

2.25 Prop Att w/FD

2.75 Prop Att w/O FD

Prop Rate

2.5 Prop FPA

f. Cueing Functions - Subjects rated the displays in regard to providing advance notice of upcoming events for each maneuver on the approach, landing and for missed approach. Averages for the missed approach reflect ratings of only two subjects.

(1) Localizer Capture

Unsuitable Suitable Highly Suitable

1 2 3 4 5

4.0

Untimely Timely Very Timely

1 2 3 4 5

3.75

(2) Glideslope Capture

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 4.5

Untimely Timely Very Timely

1 2 3 4 5

↑ 4.25

(3) Alignment

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 2.0

Untimely Timely Very Timely

1 2 3 4 5

↑ 2.25

(4) Flare

Unsuitable Suitable Highly Suitable

1 2 3 4 5

↑ 2.0

Untimely Timely Very Timely

1 2 3 4 5

↑ 2.5

(5) Touchdown

Unsuitable		Suitable		Highly Suitable
1	2	3	4	5

↑ 1.5

Untimely		Timely		Very Timely
1	2	3	4	5

↑ 2.0

(6) Rollout

Unsuitable		Suitable		Highly Suitable
1	2	3	4	5

↑ 2.0

Untimely		Timely		Very Timely
1	2	3	4	5

↑ 2.25

(7) Go around

Unsuitable Suitable Highly Suitable

1 2 3 4 5

2.5

Untimely Timely Very Timely

1 2 3 4 5

2.5

(8) Failures

Unsuitable Suitable Highly Suitable

1 2 3 4 5

1.5

Untimely Timely Very Timely

1 2 3 4 5

2.5

g. Control Authority - Subjects rated control authority for each remote control mode. Average ratings for each mode are:

(1) Pitch Axis

Inadequate Adequate Excellent

1 2 3 4 5

3.25
Prop Rate

4.37
Prop FPA

3.62
Prop Att

(2) Roll Axis

```
Inadequate              Adequate                Excellent
1             2             3             4             5
_________________________________________________________
           ↑     ↑
          1.75  2.25
     Prop Rate  Prop Att
```

(3) Yaw Axis

```
Inadequate              Adequate                Excellent
1             2             3             4             5
_________________________________________________________
                                   ↑
                                  3.5
```

h. Vehicle Response - Subjects rated vehicle response for the same control modes. Average ratings are:

(1) Pitch Axis

```
Unresponsive           Responsive      Highly Responsive
1            2              3              4            5
_________________________________________________________
                        ↑   ↑              ↑
                        |   3.0            4.0
                        |   Prop Rate      Prop Rate
                        |
                      2.75
                    Prop Att
```

(2) Roll Axis

```
Unresponsive          Responsive       Highly Responsive
1             2             3             4             5
_________________________________________________________
              ↑     ↑   ↑
              2.0   2.5 2.75
              Roll  Roll Roll
              Att   Rate Att
                         Override
```

(3) Yaw Axis

Unresponsive | Responsive | Highly Responsive

1 2 3 4 5

3.0 Override

3.25 Remote

i. <u>Control Stick Electronic "Dead Band"</u> - Subjects' average rating of the dead band is 2.75 (1=Inadequate, 5=Excellent).

j. <u>Control Stick Mechanical Breakout Force</u> - Subjects rated mechanical breakout at 2.5 (1=Inadequate, 5=Excellent).

k. Operators were asked which control, trim or the control stick, was used more frequently in the following three control modes:

(1) Proportional Pitch Attitude - All indicated that they used the trim more frequently.

(2) Proportional Flight Path Angle - All indicated that they used the trim more frequently.

(3) Yaw - All indicated that they used the proportional controller. One subject stated that yaw trim was too slow.

l. Subjects were asked if there were any input devices that they would like to have function differently such as a toggle switch instead of a push button, etc.

(1) One subject indicated that he would prefer roll trim in lieu of the yaw trim feature and that the spoiler, throttle and turn controller should be redesigned.

(2) One subject indicated that rudder pedals should be installed and that the throttle controller should be redesigned.

m. Subjects were asked if they felt that nosewheel steering and rudder controls should be on rudder pedals. Responses to this question are equally divided.

B. Pilot Factors Issues

1. Approach Sequence Indicator - One subject felt that these indications should be orientated left to right, another up to down, and the third felt it made no difference. One subject felt that the lights should be placed close to the instrument to be used as sequencing occurs; i.e., flare to the right side of the ADI, align light above the HSI or LSI, etc.

2. Television Monitor - Asked about the usefulness of the TV monitor in VFR or after breakout on approach, three subjects rated the display useless while one rated it extremely useful. Those who rated it useless indicated that it was useful for rollout and in taxi operations.

3. Color Coding - Lights - Three subjects rated color coding of the caution, warning and status lights adequate. One subject wanted a better cue for the de-roll maneuver, one wanted more noticeable changes in the approach sequence indicator and another wanted background lighting decreased around the ROS.

4. Manual Control Mode Preferences - Subjects were asked to rate the remote control modes in order of preference. All except Yaw Rate (e.) included pitch and roll axes. Ratings are:

	CONTROL MODE	RATINGS			
a.	Proportional Attitude w/o FD	3	3	3	2
b.	Proportional Attitude w/FD	2	4	2	4
c.	Proportional Rate (Pitch and roll)	5	5	5	5
d.	Proportional FPA (with roll att)	1	2	1	1
e.	Yaw Rate	4	1	4	3

Note that the flight path angle mode is preferred while rate control is disliked.

5. The three following questions required write-in answers. Each question will be listed along with subject response.

   a. What is the one property of the console you liked the least? Why?

   Inability to adjust the location of the stick, throttle, and yaw control positions. Their fixed positions dictate the operator's eye distance from the instrument panel. Their positions should be adjustable fore and aft.

   Control stick attitude. It's at an uncomfortable angle - tilt forward 10-15 degrees.

   The necessity of pushing a button to decouple an axis. It is the property which would necessitate a "go-around" in the event of low altitude failures. I would prefer to automatically get remote control in the event of automatic mode failure.

   Beam noise! A head set that fits! Excessive exterior noise (loud vibrating fan and conversation). On the console itself - the stick.

b. What is the one property of the console you liked the best? Why?

The instrument displays. It was easy to crosscheck and assimilate the information. It also provided fairly good rate information.

General instrument layout. It is easy to scan.

The instrument grouping. With the performance instruments surrounding the ADI, I found developing an effective crosscheck extremely easy. I especially found the location of the LSI and vertical tape (VVI/ground) made flaring quite easy.

The close instrument display which facilitates a fast crosscheck.

c. Should there be more or fewer displays (including auditory displays)? More ( ) Fewer ( )

If more, what displays should be added? If less, what displays should be eliminated?

Add - Yaw failure light, runway threshold indication, and master caution light for axes failures. Eliminate -Angle of attack and rollout light.

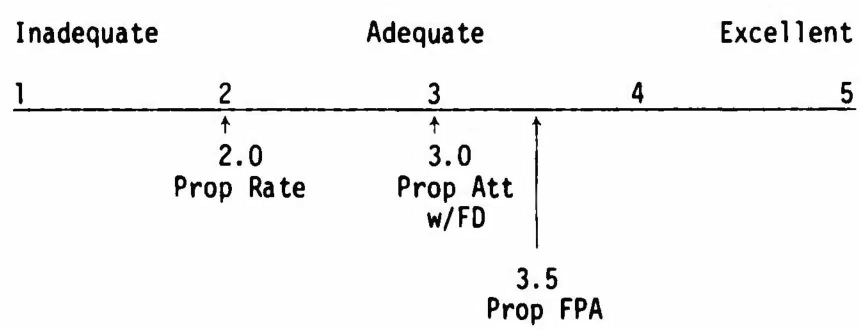
Add - Widen LSI R/W bug and display and label LSI heading bug. Eliminate - TD and rollout lights, round absolute altitude dial, command select knob (relocate).

I think the number of displays is about right. I think, perhaps, I'd like to have the axes lights (green/amber) tied to the Master Caution Light to draw my attention to the axes lights after I've decoupled one axis and had a subsequent failure. As far as I'm concerned, you can remove the rollout light (blue).

Eliminate angle of attack.

6. Control Display Configuration - Subjects were asked to what extent they felt the console geometry and control/display configuration should resemble a flight deck. One subject indicated that there was no requirement (1), and three rated it 4 on the five point scale.

7. Information Adequacy/Control Mode - Subjects rated information displays for the remote control modes. Ratings are.



8. Supervisory Override vs. Remote Control - Subjects were asked about their preference with regard to flying in a supervisory override configuration or decoupling and continuing in a remote control mode subsequent to any single axis failure. One subject indicated a preference for supervisory override, three chose the decouple/remote control option.

9. Use of Supervisory Override - All subjects indicated that they use the supervisory override feature approximately 10 percent of the time. One subject stated that he never used it toward the end of simulation. Another indicated that the automatic system consistently did a better job than he, and the feature was used only to eliminate "S-ing" during localizer and glide slope captures. All subjects also stated a desire to have the flight controls "hot" in lieu of having to turn the system on when the feature was needed.

10. Console Resemblance to Flight Deck - Three subjects indicated that the instrument displays resembled a flight deck; one stated that the TV screen, mounted above the instrument group, was where he normally looks on breakout from an instrument approach.

11. One-Man vs. Two-Man Operation - All operators indicated a need for two operators for a variety of reasons. All comments in regard to this question are listed below.

a. The second man is required to operate the data link system and monitor data link and RPV systems. He could also be of assistance with communications.

b. When three axes failures occur, the idea is not to see how good an RO might be, but to get it on the ground safely. Don't saturate on RO. Besides with a real RPV there is going to be plenty of work to spread around.

c. I think a second man is required to function as "systems analyst" and radio operator. Flying an approach remotely requires too much attention to monitor engine instrument, make radio calls, etc.

d. At low altitude, during the nitty-gritty portion of the approach, I don't have time to monitor the system operation. In fact, I might use him to align for me on a three axes failure, radio calls. Emergency Procedures. A training area for new ROs.

12. The final question in this section asked for comments on console geometry, display/control location, seating and ROS lighting. Responses were essentially a repeat of comments made on previous questions. To avoid repetition, these comments are not presented here.

C. Remote Operator Issues

1. In the following two questions, subjects were asked to identify, from a set of given failures, conditions which would cause them to abort a takeoff or execute a missed approach on landing. The question, operator response and comments are duplicated for these questions.

a. Under which of the following conditions would you decide to abort a takeoff:

If anything goes wrong on a takeoff and I am below refusal speed, I will always abort and discuss it later.

(1) Loss of visibility
Before 100 knots
On runway

(2) Excessive wind component (specify)

Can't specify because I have not seen a limit condition.

Is greater than 30 knots

Is greater than 4 degrees bank to hold runway centerline.

Something more than I've seen.

(3) Loss of instrument(s) (specify)

ADI or HSI

Any required for recovery.

LSI

Most any

(4) Loss of localizer signal

(5) Loss of communications (specify)

Don't go from bad to worse

(6) Any single axis failure (specify)

Don't go from bad to worse

Roll or pitch or power

(7) Any dual axes failure (specify)

All

Don't go from bad to worse

Roll and pitch or power

(8) Any three axes failure (specify)

Don't go from bad to worse

Roll, pitch, yaw or power

b. Under which conditions would you decide to execute a missed approach?

(1) Loss of visibility

Is less than 150 RPR; i.e., 0/0.

(2) Excessive wind component (specify)

Haven't seen limit condition

25 knot cross wind component

Is greater than aircraft limits (bank).

Greater than what I've seen

(3) Loss of instrument(s) (specify)

ADI, HSI (LSI with less than (300-1/2))

ADI, LSI, Radar Alt, HSI

Attitude indicator, VVI, radar altitude

(4) Loss of MLS

Only when IFR

(Unless VFR)

What is this?

(5) Loss of communications (specify)

Go around every time a failure occurs below 500 feet.

(6) Any single axis failure (specify)

Go around every time a failure occurs below 500 feet, except yaw.

Roll or pitch if altitude is less than 100 feet

Depends on where I am in the approach.

(7) Any dual axes failure (specify)

Go around every time a failure occurs below 500 feet.

Roll and pitch if altitude is less than 500 feet

Depends on where I am in the approach.

(8) Any three axes failure (specify)

Go around every time a failure occurs below 500 feet. Get your stuff together and try again.

Roll, pitch and yaw if altitude is less than 500 feet

Depends on where I am in the approach.

2. Turbulence Effect - Operators were asked what effect, if any, turbulence had on their ability to perform the takeoff, approach, and landing, or the missed approach. The two subjects who performed takeoffs indicated that turbulence had little or no missed effect on the maneuver. The single operator who

performed a missed approach had similar feelings for that maneuver. Comments on the approach and landing are as follows:

a. FPA indicator and pitch steering bars were almost worthless because of instability. Workload was increased, but not as much as that caused by beam noise and wind gusts.

b. Required much greater concentration and closer tracking.

c. Since you could not feel it at the ROS console, I found I had to slow down corrective inputs until I could determine what had caused the deviation. The turbulence was the hardest to analyze.

3. Control Mode Redundancy - Operators were asked to give their opinions on any control modes they felt should be so redundant that remote control would be unnecessary. One operator indicated that the roll axis should be redundant while the other three responses indicated that it would not be required in any axis. One of these three, however, stated that if one control mode were made redundant it should be bank (roll) because it was "by far the hardest to fly."

Note: Subsequent to the simulation, a roll/yaw coupling modification was made which could considerably improve roll/bank performance and reduce operator workload. Forthcoming flight tests should verify the effectiveness of this change.

4. Simulation Environment - Ratings on the working environment for simulation ranged from 3 (Adequate) to 5 (Excellent) for an average of 3.75. Elsewhere in this questionnaire and in the debriefing, subjects stated that area lighting could be improved and that the noise level was, at times, distracting. Generally, they were referring to conversations being held in the vicinity and noise of the blower fan on the room heater.

5. Operator Workload (Approach) - To a question on the point at which workload became heaviest in the landing phase, all subjects indicated 200 feet or below. Two subjects stated that this occurred at alignment (150 feet).

6. Monitoring Automatic System Performance - Subjects were asked if they actively or passively monitored performance of unfailed axes during the approach. Two subjects checked passively and one, actively; the fourth subject indicated both. One subject commented that he tended toward not monitoring at all because he "acquired faith in the automatics."

D. Miscellaneous Issues

1. Subjects were asked to rate the ability of the automatic system to control the vehicle in all axes. Average ratings are as follows:

Poor		Good		Excellent
1	2	3	4	5

- 2.75 Power
- 4.25 Pitch, Roll, Yaw

2. Subjects rated the stability of the vehicle under automatic control at 3.75 or very stable. Average ratings of automatic system performance of specific maneuvers were:

Poor		Good		Excellent
1	2	3	4	5

- 3.0 Loc Capt
- 3.5 Loc Track
- 4.0 G.S. Intercept
- 4.25 G.S. Track
- 4.75 Flare

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